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INFRA-RED PAINT DRYING PLANT IN A BRITISH FACTORY.

The illustration shows part of an infra-red lamp heating installation for rapid paint drying. The equipment comprises two 42 ft. plants, containing over 2,000 Osram infra-red industrial type lamps, and has a total loading of 500 kW.

Thermal Problems in Illuminating Engineering.

By W. R. STEVENS, B.Sc., F.I.E.S.

G.E.C. Research Laboratories.

IN designing a lighting installation the illuminating engineer is confronted with many problems other than the correct distribution of light. He must consider, for example, the availability and cost of the materials which he wishes to use, their resistance to corrosion, their weight and strength. The method of fixing the fittings and arrangements for satisfactory maintenance are further examples, but perhaps the most difficult problems of all are those associated with heating. In any lighting fitting or installation the designer must avoid overheating both of the fitting and associated cables and of the surrounds to the fitting. Since, in all commonly used electric light sources, some 80—90 per cent of the energy input to the lamps is dissipated as heat, it is evident that the designer has to dispose of a good deal of surplus heat ; in addition, of course, any light which does not escape from the fitting is converted into heat. In general it may be reckoned that more than 90 per cent of the energy consumed by a fitting will reappear as heat whether we are concerned with electric lamps or other sources of light.

The problems involved in controlling this heat can be divided into two broad groups.

(I) Heating of the surrounds and, in particular, of people lighted by an installation, and

(II) Heating of fittings and associated cables.

The thermal considerations affecting lamp design will not be discussed except where they overlap those of fittings and installations.

Fig. 1. Temperature tests on the skin. The thermo-couple for measuring temperature is strapped to the subject's forehead.

I. HEATING OF LIGHTED OBJECTS AND SURROUNDS.

Cinema Studios.

This group is of particular importance in some specialized installations such as cinema-studio sets where the high illumination intensities required can make acting very uncomfortable: the same problem has been encountered in television studios. In the cinema studio the difficulties are now overcome by the use of faster film and doubtless corresponding developments will occur in television, but some interesting experiments were being made just before the war in the use of high-pressure mercury-discharge lamps in the lighting equipment.

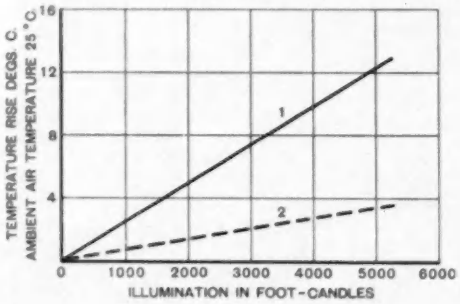

Fig. 2. Temperature rise of skin surface with theatrical make-up when illuminated by various sources.
(1) Tungsten filament lamp.
(2) High pressure, high brightness mercury vapour lamp (air cooled).

Fig. 1 is a photograph of an experiment in which an observer, made-up with suitable grease paints, was subjected to a high illumination. Strapped to her forehead is a thermo-couple to measure the temperature rise of the skin. The rise recorded was approximately 2·4 degrees C. per 1000 foot candles with tungsten lamps and 0·6 degrees C. for mercury-vapour; the carbon-arc gave values roughly mid-way between the other two. The results for tungsten filament and H.P.M.V.* lamps are shown graphically in fig. 2; these must not be regarded as absolute values, but they do provide reasonable comparative data. Probably more important is the fact that during the experiments it was found that under tungsten lighting illumination values of 2000 foot candles caused discomfort after only a few minutes exposure, whereas it was possible to remain almost indefinitely under mercury-vapour light even with illuminations of 6000 foot candles.[1, 2]

There are two reasons for these results. Firstly, as compared with tungsten lamps, the H.P.M.V. lamp radiates a smaller proportion of its energy as heat, and secondly the heat energy which is radiated has a higher proportion of long wavelength radiation which is absorbed by the glass bulb of the lamp and by the mirrors and lenses of the optical system; the second of these effects is more important than the first, but the overall result is that a given illumination of H.P.M.V. light is accompanied by much less radiant heat than the same illumination from tungsten filament lamps, and radiant heat is the main cause of thermal discomfort to a person working under a high illumination.

A convenient device for comparing the heating effects due to radiant energy in beams of light is a standard plate; this consists of a 6 inch diameter disc painted grey on the side facing the beam and having the reverse side chromium plated and highly polished. The grey paint can be varied, but a reflection factor of 50 per cent (an approximation to the average reflectivity of the human face) has been found satisfactory. A thermo-couple, soldered to the centre of the polished side, is coupled to a millivoltmeter which gives a reading proportional to the temperature rise of the plate. The device is convenient for comparison purposes because it is easily set up and maintained.

TABLE 1.

Temperature and Illumination Measurements on G.E.C. 36 inch. dia. Hospital Operating Theatre Fitting.

Fitting	Temp. Rise of Test Plate		Illumination Values (ft. candles).	
	Without filter	With filter	Without filter	With filter
Std. heat absorbing glass..	17 degs. C.	No appreciable rise	500	250
Light heat absorbing glass	17 degs. C.	5.5 degs. C.	500	400

Hospital Operating Theatres.

The hospital operating theatre is a situation in which great discomfort can be caused to the occupants by high temperatures. This is

* High-Pressure Mercury Vapour.

particularly true of the intensely lighted area on the operating table and the effects are aggravated by the protective face pieces and head coverings which the surgeons are obliged to wear.

The solution most usually adopted is to ensure that the light from the main lighting fittings passes through a thickness of heat absorbing glass (such as "Calorex") which absorbs a much larger proportion of radiant heat than of light. A disadvantage of the normal types of heat-absorbing glass is that, because of the dark green colour, the transmitted light is coloured green: also, the transmission is only about 50 per cent. A lighter form of heat absorbing glass is, therefore, often used in G.E.C. operating theatre fittings, and this is generally satisfactory; the light transmission is about 80 per cent with relatively little coloration, although the heat reduction is not so great. Table I summarises the results for standard and light heat absorbing filters used in the G.E.C. 36 inch diameter fitting. Temperature measurements were made on the standard plate described above.

The measurements are the average over a 1 foot diameter patch of light 3ft. 6ins. below the centre of the base of the fitting. The rise of 5.5 degs. C. is not serious in this experiment.

Apart from the use of heat absorbing filters, the G.E.C. fitting is designed to give low radiant heating by making the light pass through several layers of glass before it finally reaches the operating table. All the emerging light passes through at least ½ inch and some through 1 inch thickness of glass, and since glass tends to absorb the radiant heat more than the light, the emerging light is comparatively "cool." Fig. 3 shows the energy distribution from a tungsten filament lamp, the transmission of clear glass and of samples of heat-absorbing glass.

The heat which is absorbed, either by clear glass or by special filters, is finally lost from the fitting mainly by convection. The warm air thus produced will be removed by general circulation of the air and perhaps, finally, by a conditioning plant, but in any event it will cause less discomfort to the occupants than would the same amount of heat in the lighted area in which the surgeons are working.

Gauge Rooms.

In gauge rooms a constant temperature is required to prevent irregular expansion of accurate gauges. Elaborate precautions are taken to ensure constant temperature: for example, the "room within a room" method of building is used so that walls and ceilings are surrounded by an air-space and the room is entered through an air-lock. Air-conditioning is used and daylight is excluded.[3]

The main lighting requirements for such rooms are:—

(1) A high illumination of a quality which will off-set the lack of daylight, and

(2) A minimum of heating and particularly of radiant heating.

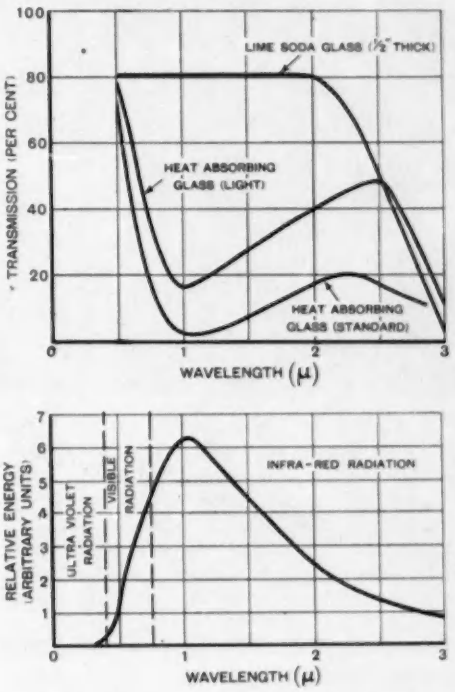

Fig. 3. Transmission curves for clear and heat absorbing glasses, and energy distribution in spectrum of tungsten filament lamp at 2,750 degs. K.

A satisfactory solution has been found in high-voltage fluorescent discharge tubes, and a typical illustration is shown in fig. 4. Five sets of tubes run the full length of the room and give a high illumination (different installations vary from 16 to 28 foot candles), well-diffused and of a satisfactory colour. The wattage required is only about half that for an equivalent illumination using tungsten filament lamps, so that the overall heating is much reduced. In addition, the total radiated energy is considerably less than for an equivalent

tungsten filament installation and is uniformly distributed.

An alternative source would be the 5 foot low-voltage discharge lamp which has been found satisfactory for similar work. Even for more ordinary industrial processes this lamp has found great favour because of the impression of coolness which it gives.[4] The effect seems to be a combination of the low radiant heating for high illumination and the psychological effect of a light approximating in colour to that of daylight. Light with a high proportion of blue in it is accepted by most people as "cool" whereas yellows and reds are regarded as "warm."

Fig. 4. Lighting with fluorescent discharge tubes in an aircraft gauge room.

"Carbon" Printing.

The reduction of radiant heating is often important for inanimate objects as well as for human beings. An interesting example is found in the "Carbon" printing process where the higher the illumination the faster can the printing be done. High illumination brings with it, however, high temperatures of the carbon tissue which are undesirable. For such processes H.P.M.V. lamps are giving good results.[5]

Where the surrounds to a fitting are likely to be damaged by overheating, the designer must, of course, exercise great care. An important example is wood-panelling, particularly on board ship, where the most stringent temperature conditions are often imposed because of the high risk of fire.

II. HEATING OF FITTINGS AND ASSOCIATED CABLES.

The control of the temperature of the immediate surrounds to a lighting fitting involves at once the control of temperatures in the fitting itself.

In all fittings it is important to consider the heating effects, and almost always the task is to avoid over-heating. Sometimes it is necessary to comply with some legal requirement—as with fittings for use in explosive atmospheres—sometimes to avoid less dangerous, but nevertheless expensive, results of overheating such as deterioration of rubber insulated cables. Often the thermal effects can be calculated while the fitting is being designed on the drawing-board;[6] sometimes, however, elaborate experiment and measurement are required to get a satisfactory performance. In any event an endeavour must be made to avoid overheating of the component parts of the fitting.

The fitting has to dispose of as much energy as the lamp gives to it, and it has been seen that only a little of this energy will be lost as light. There are only three ways in which the energy can be dissipated: conduction, convection and radiation. Conduction is of small importance in removing heat from the fitting and its associated leads because there is usually very poor thermal contact with the surrounds; even a "down-rod" type of fixing conducts away only a small proportion of the heat. (Conduction is, however, of importance in transferring heat from one part of the fitting to another).

Radiation and convection depend upon the area, shape and nature of the outer surface of the fitting as well as the temperature, and in any fitting when the lamp inside is switched on the surface temperature will rise until the steady state is reached at which the energy lost from the fitting is equal to the energy consumed in the light source. The greater the area of the surface and the more freely it can lose heat by radiation and convection, the lower will its temperature be in the steady state with a given wattage of lamp. Therefore the fitting should be as large as possible with a finish which encourages radiation. The

reasonably possible variations in fitting shapes have comparatively small effect on convection once the overall area is fixed. Large areas of clear or translucent glass are of great value because the loss of heat by direct transmission (particularly heat of short wavelength) is high.

An idea of the effect can be obtained from the results of the following experiment in which surface temperature measurements were made on a 16 inch diameter clear glass sphere and a metal sphere 19 inches diameter with the results given in Table 2.

TABLE 2.

Average temperature rise of outer surface of glass and metal spheres: ambient temp. 25 degs. C. still air.

Material	Surface area	Lamp	Temp. rise
	sq. ins.	watts	Degs. C.
Glass	800	1000	46.5
Metal ..	1130	1000	154
Metal ..	1130	200	50

The metal had a dull copper finish. Dull black reduced the temperature rise from 50 degs. C. to 37 degs. C. with a 200 watt lamp.

Thus, although the glass sphere was considerably smaller than the metal it was able to dissipate some five times the energy for a given surface temperature.

Surface temperature, however, is not the only consideration, for the larger the fitting the more costly and difficult it is to handle, and even if the overall dissipation of heat is great, it is still possible for individual parts of the fitting to be overheated. The most important of these parts is the flexible cable connecting the fitting to the main wiring. If this cable is overheated, then in course of time the rubber will harden and may flake off, allowing the metal conductors to short-circuit. If the lamp cap in an electric lamp is overheated the cement may lose its strength, so that when the lamp is removed it is wrenched away from the cap which is left in the holder. Other troubles are that the solder on the lamp cap may soften and, on cooling, adhere to the lampholder; the springs of the lampholder may weaken, giving contact troubles; the lamp itself may have a shortened life if overheated.

When the temperature of the exterior surface of a fitting is fixed by the shape and nature of the surface, the temperature at any point inside the fitting is determined by the resistance to heat flow from that point to the outside. For example, if the lampholder is free to radiate it will be cooler than if surrounded by a heat insulator, just as a hot water tank loses its heat more rapidly if unlagged than if lagged. Thus a lampholder in a porcelain body will be hotter than if the bare lampholder shell were used.

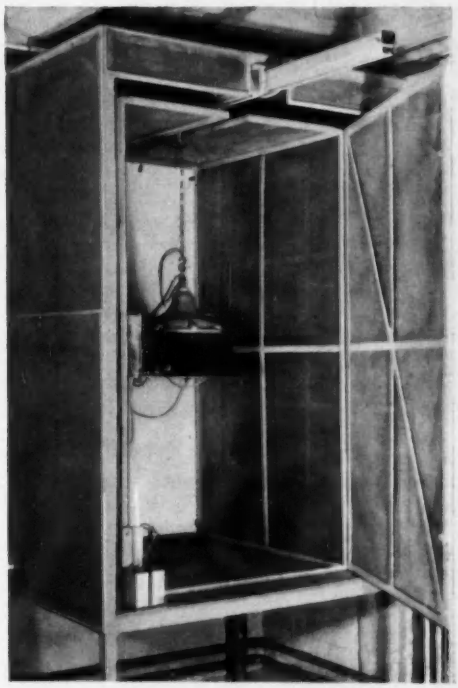

Fig. 5. Enclosure for temperature measurements.

Unfortunately, good electrical insulators are also good heat insulators so that the provision of good electrical insulation often tends to encourage high temperatures.

Still air is also a good heat insulator. It is important, therefore, to ensure that no hot air pockets are allowed to form inside the fitting because the lagging effect of such pockets is considerable. If, however, the air can circulate freely inside the fitting, heat will be carried, by convection, from one point to another, and if the design is correct the transfer will be from points where low temperatures are important to less critical points.

Before examining some of the ways in which these results are achieved, it will be of interest to consider methods of measurement and testing of the heating effects.

Temperature Measurements.

Temperature measurements are made in large double-walled enclosures, as illustrated in fig. 5. The walls of the enclosure are made of perforated zinc so that there is a free passage of air to the fitting, but no draught which might produce erratic and inconsistent results. In practice, lighting fittings are usually subjected to draughts so that the laboratory measurement gives a useful margin of safety ; it is, of course, unsafe to rely on draughts to cool a fitting.

The inner chamber is 3 ft. square by 5 ft. high and on the door, screened from direct radiation from the fitting under test, is a thermometer to measure the ambient (air) temperature of the enclosure. The fitting is placed roughly at the centre and to it are connected a number of thermo-couples which run back to a junction box (half-way up the left-hand side), and a cold junction (left-hand bottom corner) contained in a vacuum flask with a thermometer. Thermo-couples are made of iron and "Eureka" No. 26 S.W.G. wires, and the form of the junction depends on the measurements being made. Where the junction can be inserted into the material under test, the wires are generally arc-welded forming a small ball some 1/32 inch diameter. For most work, however, surface temperatures are required, and then a strip thermo-couple is used, the ends of the two wires being rolled flat and welded together. It is important to get good contact between couple and material. Usually this is achieved by a spring or a rubber band pulling on opposite sides of the thermo-couple ; a drop of light oil also helps in obtaining good thermal contact.

When measuring the surface temperature of glass or other transparent material, it is important to make sure that direct radiation through the glass on to the couple is not giving false results, and the temperature rise due to this effect must be assessed. One method of doing this is to switch off the lamp and measure the temperature immediately on switching ; the temperature thus measured is substantially the surface temperature required. A correction to this temperature can be obtained by plotting a cooling curve—temperature against time—and thus estimating the temperature fall between switching off the lamp and measuring the temperature, but if the thermo-couple is small the correction will generally be negligible, and the errors involved will almost certainly be less than those due to the difficulty of getting good contact between thermo-couple and glass.

The voltage developed by the difference in temperature of the hot and cold junctions of

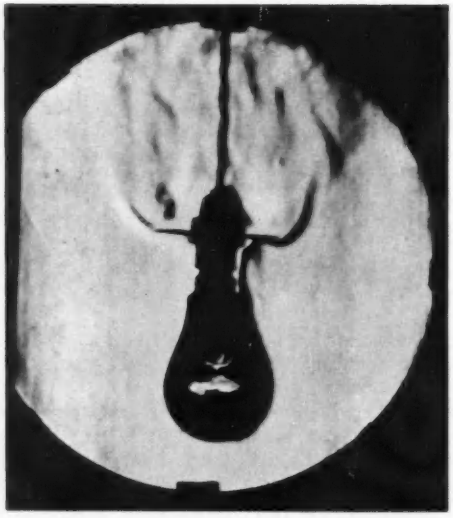

Fig. 6. Schlieren photograph : convection around bare lamp and baffle.

Fig. 7. Schlieren photograph : convection around simple fitting with baffle.

the thermo-couple is measured with a potentiometer, and from previous calibration the temperature rise of the fitting is determined, taking into account cold junction and ambient temperatures. When the fitting is first switched on it will take some time to reach its stable temperature; this may be several hours in a heavy fitting, and periodic readings should be taken to ensure that the steady condition has been reached before the final temperature is recorded.

This procedure for temperature testing has now been standardised by the British Standards Institution[7] in connection with tests on flameproof lighting fittings, and is used by many laboratories.

Examination of Convection Currents.

It is valuable to have a detailed knowledge of the convection currents operating round a fitting, and a particularly interesting method of attack on the problem is the "schlieren" method suggested by Foucault in 1859 and used in modified forms by present day workers.[8] The principle used is to form an image by means of a lens or mirror of a sharp-edged stop illuminated by a condenser system. At this image a second similar stop is placed so that only a part of the light can pass through; this light is projected on to a screen by a suitable optical system to form an image of the main lens or mirror. The fitting under test is placed between this main lens or mirror and the second stop, so that convection currents rising from the fitting produce changes in refractive index of the air through which the beam of light passes. These changes in refractive index deviate the rays of light forming the image so that some of the light which would pass through the second stop is now intercepted by the opaque surrounds of the stop, forming a dark patch on the screen; also some of the light which was previously intercepted now passes through the stop to form light patches on the screen. Thus the projected image shows the fitting under test together with a series of light and dark streaks* representing changes in refractive index and showing the course of hot-air streams rising from the fitting. To obtain a complete understanding of the method, reference must be made to fuller descriptions, but the type of result obtained is shown in figs. 6 and 7.

The most striking result which this work discloses is the way in which heat streams hug the outer surface of a fitting and, if allowed to do so, run close to the flexible cable for two or three feet of its length. This naturally leads to experiments with baffles to deflect the heat stream. Fig. 6 shows that some deflection is effected, but that eddies develop above the baffle so that some of the hot air reaches the leads. If the baffle disc is sufficiently large a useful reduction in lead temperature can be produced.

Fig. 8. Three-tier canopy using baffle principle.

An interesting example of design using, among others, the baffle principle is shown in fig. 8. The canopy consists essentially of three horizontal baffles giving a large surface and having a neat appearance. The bottom baffle fits closely to the lamp neck in order to intercept the convection stream rising from the lamp. The middle baffle is in good thermal contact with the lampholder, and by conduction cools both holder and lamp cap; the top baffle is also attached to the lampholder for the same reason. In addition, the lampholder is free to radiate and no hot pockets can form. There is, clearly, an elaborate interchange of heat between the three baffles and the rest of the fitting, but the overall result is a very satisfactory canopy from the thermal aspect.

Ventilation.

The three tier fitting shown in fig. 8 does not attempt to obtain cooling by ventilation. If such an effect is required it is necessary to

* Hence the name "schlieren" which is German for streaks.

provide a good through draught by having large apertures both at the top and the bottom of the fitting, for if hot air is to escape at the top there must be provision for cold

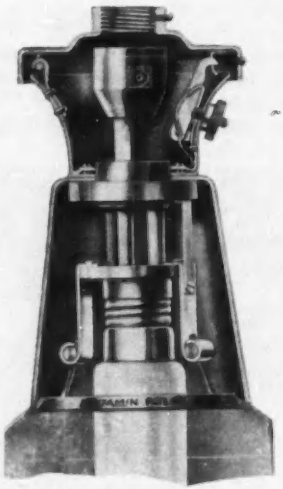

Fig. 9. "Saaflux" fitting.

air to enter at the bottom. It is not sufficient to put holes only at the top, but holes at the bottom of a fitting may be combined with a loose fitting canopy to provide sufficient outlet for hot air. The main disadvantage of ventilated fittings is that they tend to collect dirt readily, although this may be partially offset by ease of cleaning if the holes are large enough to give easy access to the fitting interior.

Modern practice tends towards non-ventilated fittings except where large apertures are required for optical reasons.

Flexible Cables.

The most frequent difficulty has been stated above to be the cooling of the flexible cables to the fitting. Much work has been done on the subject,[9] and many means are used for overcoming the trouble. Where standard methods, such as baffles and large radiating surfaces, prove insufficient to keep the temperature low enough for rubber insulation, other insulated materials can be used. Asbestos and glass fibre insulations are useful,[10] although they cannot always be used in damp (particularly salt) atmospheres because of their hygroscopic properties. The future may see improvements in this direction. Beaded leads are also employed. Such special insulators are used in short lengths running to a cool terminal block.

Difficulties arising from deterioration of insulation can often be avoided if the conductors are separated and spaced apart so that they cannot touch. This principle is shown in fig. 9 in a "Saaflux" fitting, where it is combined with an ingenious arrangement for easy removal of the lamp and reflector. The conductors near to the lampholder are of solid metal spaced apart by insulating blocks which withstand a comparatively high temperature. On releasing a catch the connectors come away with the lamp and reflector; the flexible cables enter higher up in the fitting in a cooler region.

A baffle fitted round the lamp neck prevents a hot air pocket forming round the lampholder. The baffle also makes it impossible to touch the lampholder when the fitting is assembled. It is, therefore, safe to use a lampholder without an insulated covering so that it is free to radiate. The design is very successful in achieving its objects and it will be noticed that it is a non-ventilated fitting in spite of the fact that the reflector usually has a large open bottom which might have been taken as a basis for a ventilated fitting.

The safe operating temperature for rubber insulation is usually taken as 50 degs. C. based on the standard I.E.E. ambient temperature of 32·2 degs. C.[9] This allows only 17·8 degs. C. temperature rise and is often

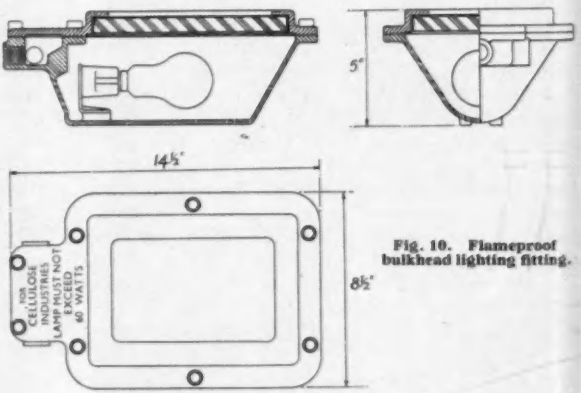

Fig. 10. Flameproof bulkhead lighting fitting.

an impossible requirement with fittings of reasonable size and price. It is, however, unnecessarily stringent for many purposes. Few situations have an ambient temperature of 32·2 degs. C. (90 degs. F.) for more than a few hours in the year. For offices and similar interiors the average is likely to be nearer 18·3 degs. C. (65 degs. F.), so that an extra margin of the order of 10 degs. C. may often reasonably be allowed on temperature rise. It is important, therefore, to choose fittings having regard to the air temperature likely to obtain in the region of the installation. In particularly hot situations it may be necessary to use insulation other than rubber (*e.g.*, asbestos), although heat-resisting rubber is now available designed for a maximum safe operating temperature of 65 degs. C.

Even if rubber insulation perishes it is not certain that a short circuit will occur. The hardening process in the rubber is likely to be comparatively slow and a good maintenance staff should detect this hardening before it has gone so far that the rubber begins to flake off. This is, of course, no excuse for a badly designed fitting, but in general a compromise must be made between freedom from trouble and cost and nature of fittings.

Flameproof Fittings.

An important group of fittings for which careful thermal design is required is that for use in situations where explosive or inflammable materials are used.[3, 7] In such situations high surface temperatures of fittings may cause fire or explosion. The temperature inside the fitting is not important because the design is such that if ignition occurs inside the fitting it can only spread out through a small air gap between flanges, and in doing this will be cooled sufficiently to prevent the flame reaching the external atmosphere: this is the basic principle of flameproof fittings and is substantially all that is demanded by the Board of Trade Mines Department, for fittings to be used in atmospheres of pentane, petroleum vapour, and coal gas. But for use with methane and acetone (including the cellulose industries) the maximum permissible temperature rise on the outside of the fitting is 50 degs. C.

Such fittings are generally heavy and large for the wattage dissipated, particularly in bulkhead types where the area of glass is relatively small. A typical fitting for a 60 watt lamp is shown in fig. 10.

Thermal Endurance Tests on Glassware.

The final problem which will be considered here is the effect of high temperatures on glass. The effect of high temperatures on glass articles is by no means fully known quantitatively, so that it is difficult to state the maximum safe operating temperature for a new design, particularly one having sharp corners or edges. For such designs standard tests are made on representative samples of completed fittings to ensure that they will be satisfactory in service. A "forced" test is necessary to get results quickly, since defects may not show themselves for many months or years of ordinary service, and then perhaps only if a particu-

Fig. 11. Artificial rain-splash test.

larly unfavourable combination of circumstances occurs.

For interior fittings using diffusing glassware, such as opal bowls, the British Standards Institution has laid down a specification[11] based on a long series of experiments.[12] In this test the fitting is required to survive, without breaking, immersion in water at 55 degs. C. after burning for one hour. The test is not intended to show that fittings will withstand rain or water-splash but to test their thermal endurance in ordinary service.

Exterior fittings are, however, subject to rain, and to prove them they are subjected at the G.E.C. Research Laboratories to a test in which the fitting, burning at its normal operating temperature, is sprayed with water at a standard rate from a specially designed nozzle. Fig. 11 shows a fitting undergoing this artificial rainstorm. Experience is necessary to correlate the test with practical conditions. In general the test is a more severe one than would occur in practice, for the spray gives a rainfall equivalent to 40 inches per hour which is some four times as great as the maximum recorded natural rainfall.

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Electric Furnaces for Heat Treatment of Metals.

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THE enormous production programmes which have been embarked upon during the last four years have confronted the production engineer and metallurgist with a great variety of plant and process problems. Many of them have been of so vital and urgent a character as to demand immediate solution, without the progressively planned experimental and development work which would normally precede the design and installation of large scale manufacturing plant.

It is not surprising, therefore, that the solution of many of these production problems, on which our very existence has depended, has been arrived at more by improvisation and adaptation than by fundamental discovery or invention. Processes have been applied to analogous jobs on a scale which would not have been regarded as reasonable in more normal times without experience with smaller pilot installations.

For these reasons a very great increase in the use of electric furnaces for the heat treatment of metals has been made possible.

There has also been a marked increase in the unit size of electric heat-treatment furnaces and in the number of furnaces installed, but it is perhaps the extent to which they have been adapted to new processes and applications which is most impressive. These developments have been perfectly logical and reasonable. Naturally, experience gained on comparatively small furnaces has been applied to much larger ones. A special type of furnace which

was designed and built for nitriding engine crank shafts without distortion was found in practice to have characteristics which made it particularly suitable for another and entirely different application. The first electric furnaces designed to work with an artificial gas atmosphere were made for bright annealing and hardening without scaling. Success with these led quite naturally to furnaces for nitriding, gas carburising, brazing, the special processing of malleable iron, and for certain applications in connection with powder metallurgy.

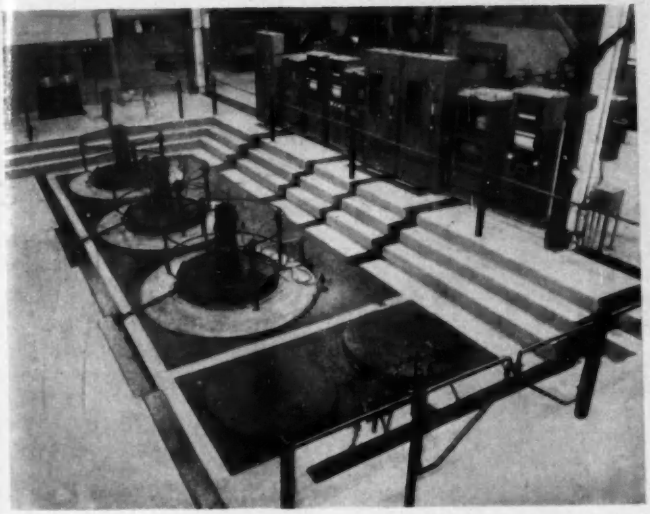

Fig. 1.—Vertical cylindrical nitriding installation.

Then there have been interesting cases of improvisation and adaptation of electric furnaces on quite a big scale for special process work solely because furnaces of a particular type happened to be available at the time, due to inability to ship them to the country for which they were intended, owing to changed military circumstances. These furnaces have proved so successful that their use for the purpose to which they were put bids fair to become established practice. Incidentally, these few examples of the growth in the applications of electric resistance furnaces are a fair commentary on their really extraordinary versatility.

Electric furnaces are playing a very important part in the world to-day, and when the restraint imposed by war conditions is removed, an account of their contribution to the war effort will be very impressive; meantime it is possible to indicate some part of the progress which has been made by reference to certain recent installations.

The installation shown in fig. 1 is used for nitriding the cylinder liners of a well-known aircraft engine. It consists of three vertical cylindrical electric furnaces with automatic temperature control gear, gas control cubicles and sufficient containers to enable the furnaces to work continuously.

The parts which are surface hardened by the nitralloy process in these furnaces are of such a delicate design and proportions that the greatest care has to be taken in supporting them in the furnace so as to avoid any possibility of distortion. This is achieved by loading the pieces on the special heat-resisting alloy castings shown assembled in fig. 2. With this arrangement, the use of jigs is dispensed with. Uniformity of temperature

Fig. 2.—Heat-resisting charge support assembly.

throughout the charge is essential, and is successfully obtained without dependence on the skill and attention of the operator. In this way distortion is avoided and a perfect uniformity of hardness ensured. A very simple and effective closure of the nitriding pot is obtained by means of a water-cooled rubber ring and four bolts, all of which are outside the furnace. This is an important feature, since it not only gets rid of all the troubles and defects of sand or oil seals (or, alternatively, of the usual gasketed joint with numerous bolts), but it enables loading and unloading to be effected by one man in a very few minutes. Each furnace is self-contained with its own automatic temperature control panel, switchgear, ammonia gas control cubicle and gas supply line. Temperature, gas flow, gas pressure, etc., are under precise control and previously established operating conditions can be repeated with accuracy.

Fig. 3.—Electric, gas and automatic temperature controls.

The furnace heating elements, which are of large diameter nickel-chromium wire in the form of coils and completely surround the pot, are arranged for star/delta control, so that the input to the furnace can be reduced to approximately one third during the "holding" period. The automatic temperature control gear is of the single-zone type. In addition to the indicating control instrument there is a recording pyrometer for each furnace. The control panels are shown in fig. 3.

The switchgear for each furnace is enclosed in a steel-plate cubicle with removable back cover and hinged glazed doors. It comprises one triple-pole isolating switch which is fully interlocked with the door of the case to prevent access to live parts, and electrically interlocked with the line contactor to prevent the isolating switch breaking the main current; one triple-pole airbreak contactor fitted with powerful magnetic blow-outs and substantial arc chutes of heavy duty rating; one set of three overload releases of the adjustable magnetic type with oil dash pot time lags; control circuit fuses, terminals, pilot lamps, push button control switch, etc.

A second installation is shown in fig. 4. This is a 100 kW continuous roller hearth type furnace for refining and hardening gears. The working temperature varies be-

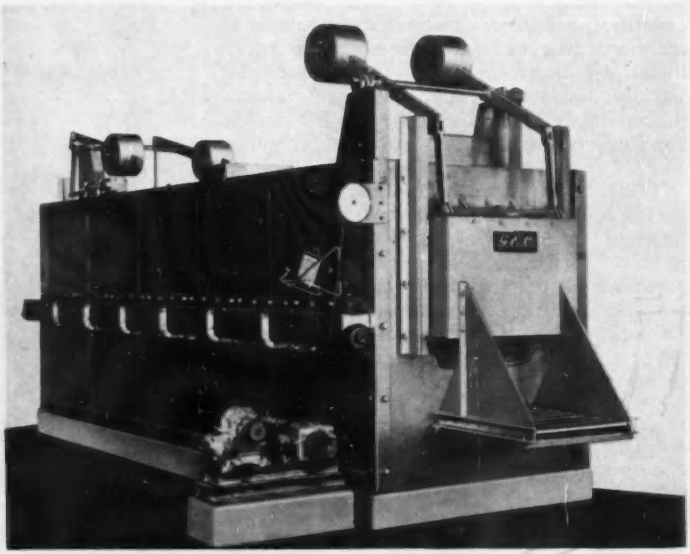

Fig. 4.—100 kW continuous roller hearth type electric furnace, 15ft. by 2ft. 3ins. by 1ft. effective working space.

tween 760 degs. C. and 900 degs. C., and the gears are carried in trays which pass through the furnace on rollers which are driven by the worm gear shown in fig. 5. The temperature at which the gears are quenched is critical. It is on this account that a photo-electric cell is mounted near the discharge end of the furnace to give an audible signal to the furnace operator when a tray is ready for unloading. The furnace doors are pneumatically operated by means of foot levers.

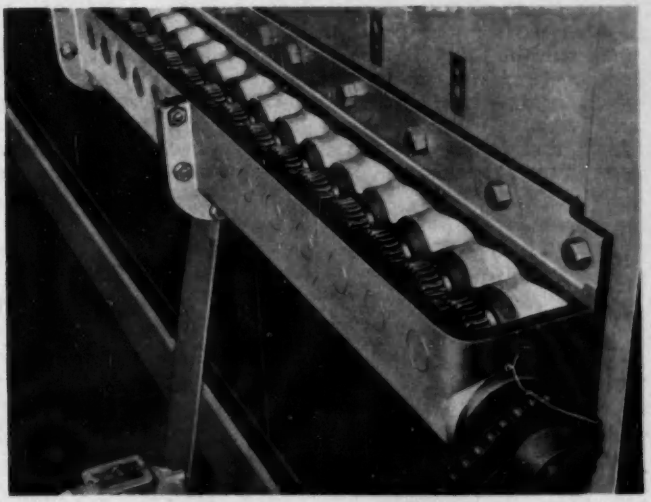

Fig. 5.—Section of roller hearth drive.

Fig. 6 shows a 180 kW chain conveyor type continuous furnace used for heating aluminium alloy billets of widely varying size of forging. This furnace possesses some interesting mechanical features. The conveyor consists of a number of troughs fitted on chains across the width of the furnace ; the troughs are split up into five equal sections and one billet is laid in each section.

At the discharge end of the furnace the billets are delivered into a common channel where they are kept at the target temperature until they are removed. The arrangement

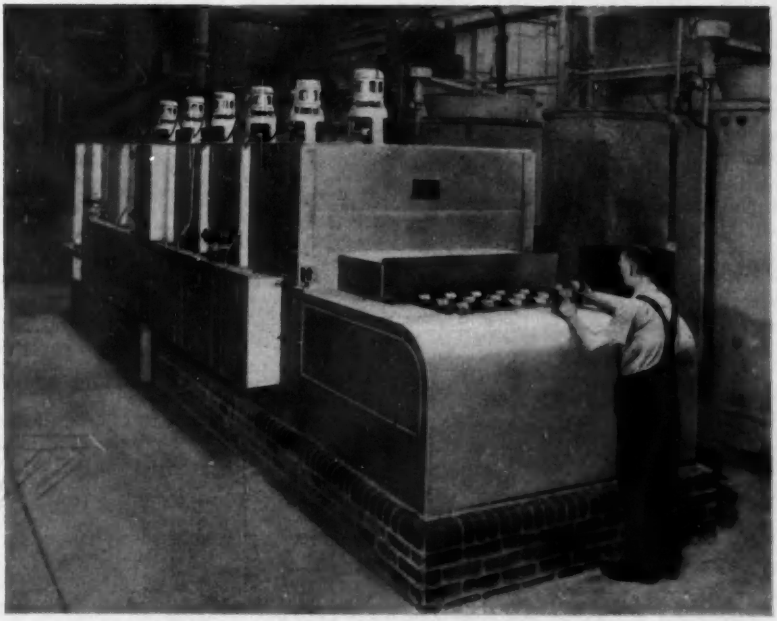

Fig. 6.—180 kW chain conveyor type, continuous billet heating furnace, 20ft. by 3ft. 6ins. by 9ins. clear working height.

is such as to take care of possible inequalities in time taken for the process which follows that of heating the billets. No matter how long a time is spent on this subsequent process, the billets awaiting withdrawal are retained at the correct temperature. This furnace works at a comparatively low temperature, and it is essential that the billets are heated uniformly; hence, the use of fans within the furnace chamber.

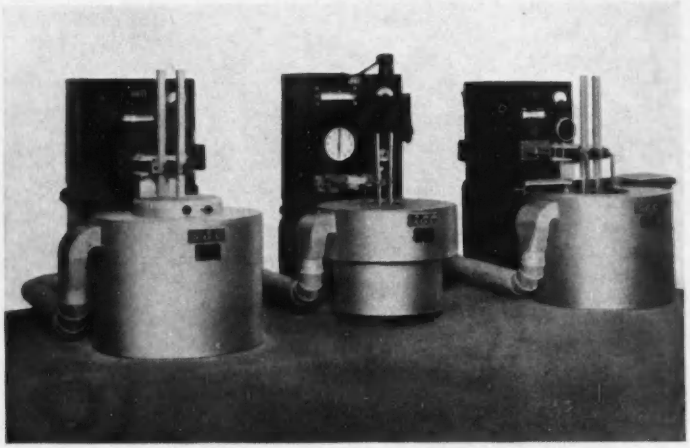

Fig. 7.—Set of three electrode type salt bath furnaces for high speed steel tool hardening.

Reference has already been made to an installation for the case-hardening of aero engine cylinder sleeves by the nitralloy process which consists essentially of subjecting finish machined parts to the action of ammonia gas in an electric furnace which is held at a temperature of 500 degs. C. This is obviously a gas case-hardening process and, incidentally, it has replaced the older method of case-hardening by pack carburising in the manufacture of many important components made of steel. There are still, however, a very large number of the old type of pack carburising plants in use. A recent development in this connection has been the gas carburising process which has several distinct advantages over the pack process, and will doubtless find increasing use in the near future. It is simpler, more efficient, susceptible to more precise control and very much cleaner. The electric furnace has played an important, though not exclusive, part in making a practical success of this process. Batch type electric furnaces, and particularly those of the vertical cylindrical type, offer all the essential requirements of the process which includes precise temperature control, uniform temperature distribution, constant and uniform gas circulation, etc., all of which are obtained and maintained automatically and with a certainty which enables previously successful treatments to be repeated exactly. The G.E.C. gas carburising pot has a very simple and effective method of closure. In addition to a wide general field of application, this electric gas carburising process will have a particular appeal when it is desirable to avoid distortion in the case-hardened components. This can be done by suspending the pieces being treated or by supporting them on jigs or specially designed supporting media similar in general type to that shown in fig. 2. In fact, much of the experience which has been gained with nitriding plant is proving very valuable in this further new field. The gas atmosphere producing plant used for this process is very susceptible to control; thus its product can be adjusted to give the desired carbon content in the case, and with the aid of the automatic temperature control gear, any practicable depth of case can be obtained.

There has been a very large increase in the use of electrode type salt baths during the last three or four years. They may be divided into two main types which are suitable for high and low temperatures respectively. The high temperature furnaces are used chiefly for

hardening high speed steel tools, and are designed for working temperatures of 1,200 degs. C. to 1,400 degs. C. The low temperature furnaces are used for pre-heating high speed steel tools before they are immersed in the high temperature furnace, for "hot quenching" certain of these tools after withdrawal from the hardening furnace and for the hardening of carbon steel tools and cyanide hardening of small steel components. They are generally suitable for temperatures of 500 degs. C./1,000 degs. C. Their chief virtue lies in the speed with which tools can be heated and the total absence of scaling which is liable to destroy fine cutting edges.

One installation of three of these furnaces is shown in fig. 7. The furnace shown on the left is used for pre-heating the tools, the middle one is the high temperature hardening furnace, and that on the right is used for hot quenching. In some instances the pre-heating is done in a muffle type furnace and, frequently, the third furnace is dispensed with and the tools are quenched in oil.

Fig. 8 shows a new three-phase low temperature salt bath furnace, rated at 40 kW, which deviates from the conventional shape of these furnaces, which are usually circular in plan. This is a rectangular furnace with a free working area 18 inches by 8 inches, with a normal salt depth of 16 inches. This is a convenient shape and size for many purposes. The insulated split type lid can be operated by the movement of a single lever.

Many people have gained experience with electric furnaces during the stress of the last three or four years, some willingly and some unwillingly. Most, if not all, of them now appreciate the inherent properties and advantages of electric resistance furnaces. Furthermore, this is the result of personal experience and not of propaganda. Consequently there is far more co-operation between the electric furnace builder and actual and potential users than ever before. This experience and co-operation can have no other effect than to increase the proportion of electric to fuel-fired furnaces in the future.

This article has been restricted to a consideration of electric resistance furnaces. The author has deliberately refrained from dealing with the development of high frequency induction heating as applied to metallurgical problems because its scope is sufficient to justify separate treatment.

While it has been possible, in existing circumstances, to give no more than a general indication of the growing field in which the electric furnace has found ever-widening application, enough has probably been said to establish its impressive versatility and to foreshadow its future uses.

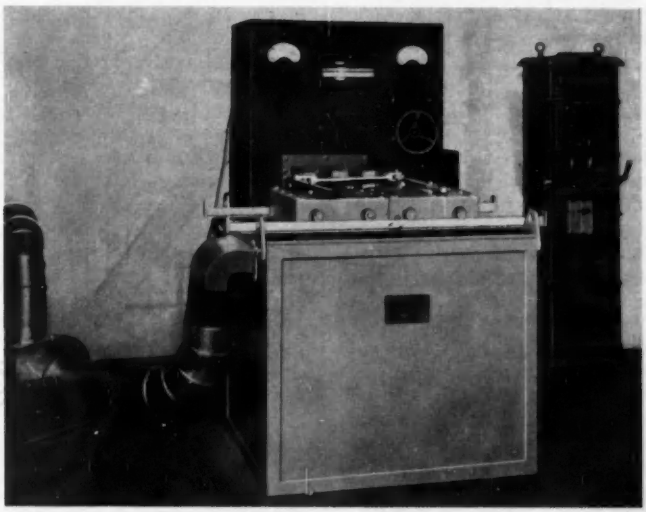

Fig. 8.—40 kW, 3-phase low temperature electrode type salt bath furnace.

The Processing of Glass in the Lamp and Radio-Valve Industries.

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INTRODUCTION.

GLASS is made by heating an intimate mixture of oxides, known as "batch," to a high temperature in large furnaces. The number of constituents and the relative proportion of each varies considerably with the type of glass required.

The molten glass thus founded in the furnace is fashioned either by machine or by hand into various solid forms. Many articles, such as bottles, window glass and domestic ware, are produced in the glasshouse ready for use directly from the furnace. Other articles serve as the raw material for subsequent treatment in a wide variety of industries. In this latter class, scientific apparatus and medicinal ampoules are made from glass tubing, and the radio valve and electric lamp industries are dependent upon the production of glass bulbs, tubing, rod and pressed blanks by the glass factories. Radio valves, cathode ray tubes, electric lamps and other electronic devices are characterized by the sealing of metallic conductors through the glass wall of an envelope to produce vacuum-tight joints.

About half a century ago, such joints could be made only by skilled craftsmen using hand methods, and platinum was the only metal which made a satisfactory seal through glass. The high cost of platinum and its restricted application stimulated the search for substitutes, and to-day manufacturers can choose from a fairly wide range of glass-metal combinations for the fabrication of satisfactory seals. At the same time, the required rate of production of lamps and valves has outgrown the capacity of skilled labour, and means have been devised to replace their expert manipulation by mechanical processes wherever possible. Mechanization almost invariably results in a product of more uniform quality, produced at speeds considerably beyond the capabilities of hand labour.

1. GLASS—THE WORKING MEDIUM.

A. The Nature of Glass.

Glass is often glibly described as a supercooled liquid, without any further qualification. Such a description can be misleading for it creates the impression that at room temperatures glass retains a degree of plasticity which permits it to undergo distortion without harm.

For a better appreciation of the nature of glass it is necessary to consider its behaviour at various temperatures.

The temperature at which the glass is formed is called the "founding temperature," and this varies from about 1400 degs. C. for the "soft" lime-soda glasses to about 1550 degs. C. for the "hard" borosilicate glasses.

At the founding temperature, glass is definitely liquid, but the flowing properties of the liquid (that is, its viscosity) vary somewhat with the composition. In general, the viscosity is comparable with that of golden syrup at room temperature.

As the temperature of the glass is decreased after founding, the viscosity increases rapidly and the glass behaves as a plastic solid which can be manipulated or blown into various shapes. As the temperature is decreased still further the viscosity continues to increase, and it becomes more and more difficult to work the glass until finally a stage is reached where the glass will not deform at all readily, but still retains a slight degree of plasticity. The range of temperature over which this occurs is a most important characteristic of all glasses and is referred to as the "annealing range."

The annealing range can be defined as follows. The upper limit is a temperature at which internal stresses can be relieved at the maximum speed without bulk distortion. The lower limit is the lowest temperature at which viscous flow is at all appreciable.

If sufficient time is allowed, two glass surfaces under pressure will adhere at tem-

peratures just exceeding the lower annealing temperature. This technique is sometimes employed in the manipulation of components which have optically-worked surfaces.

Below the annealing range glass must be regarded as a solid which becomes more and more brittle as the temperature is decreased until at room temperatures it assumes its familiar form as a material which cannot be appreciably deformed without fracture.

wider this range is, the less critical will the processing need to be.

Thus, from the production engineer's point of view, a satisfactory glass is one of which the working range is wide, and within the compass of readily available heating devices, and of which the annealing temperature is sufficiently low to enable annealing plant to be operated in an economic manner.

The important temperatures for a selection of glasses are given in Table I.

TABLE 1.

Characteristic Temperatures for Different Glasses.

	L.1	X.4	H.H.	W.1	H26X	Pyrex
Type of Glass	"Soft" Lead Oxide	"Soft" Lime-Soda	Heat-resisting or "hard" Glasses			
Melting Temp. Degs. C.	1350—1400	1400—1450	1450	1450	1520	1550
Working range Degs. C.	980—680	1020—740	1170—850	1150—830	1260—1000	1250—870
Annealing range Degs. C.	420—300	520—400	600—500	570—450	720—600	620—500

NOTES: (a) With the exception of Pyrex, all the above glasses are made by the G.E.C. Ltd.

(b) The temperature characteristics of X.8 glass are not included because they are almost identical with those of X.4.

To sum up, glass is a substance of which the viscosity varies continuously with temperature. In this respect it is unique. The viscosity varies over an enormous range, but for practical purposes the range can be considered to cover four distinct phases.

(i). The liquid phase, extending from the founding temperature to a temperature where the glass is just sufficiently plastic to be controlled.

(ii). The plastic phase, in which the glass can be worked and blown in a controllable manner. This phase is important and the corresponding temperature limits define what is known as the "working range."

(iii). The annealing phase, which covers the transition from the plastic to the solid phase. Within the annealing range of temperatures, glass is virtually a ductile solid.

(iv). The solid phase which covers all temperatures below the annealing range. In this phase the glass cannot be subjected to excessive deforming stresses without fracture.

It is clear from this that any processing of glass which involves a change of shape to some predetermined form must be carried out at temperatures within the working range. The

B. The Strength of Glass.

If a rod of iron or copper is stretched, the extension (or strain) is proportional to the stretching force (or stress) up to a certain value of stress known as the "yield point." Above the yield point, the strain is no longer proportional to stress and the rod becomes permanently stretched.

A ductile material such as copper can be stretched a good deal beyond the yield point before failure occurs, but a brittle material such as glass breaks almost immediately the yield point stress is exceeded.

The yield point for glass in compression is approximately ten times greater than the yield point for glass in tension. It follows that glass will break more easily in tension than under compression, and that tensile forces should be avoided wherever possible.

An important property of glass is its low thermal conductivity. The value is about 1/500th that of copper and about 1/100th that of mild steel.

When a solid body is heated from the outside, a thermal gradient is established within the thickness of the material, the centre portion being at the lower temperature. The gradient is steeper when the material is a

poor conductor than when it is a good conductor. A state of stress will exist wherever there is a thermal gradient, because the cold portions will restrain the expansion of the hot portions. The cold portions will thus be in tension and the hot portions in compression.

The magnitude of the stress is directly proportional to the coefficient of thermal expansion of the material and varies inversely with its thermal conductivity. For the latter reason it will be seen that glass when heated is particularly prone to the formation of internal stresses, and, being brittle, is liable to crack. The most desirable way of reducing the stress is to lower the thermal expansion.

Thus heat-resisting glassware has a thermal expansion of approx. $3{\cdot}5 \times 10^{-6}$ per degree C. compared with "soft" soda glass at 10×10^{-6} per degree C. It is obvious that the former glass will be able to withstand a considerably greater thermal shock than the soft glass.

Thermal or mechanical stress will more readily cause the fracture of a glass component if it possesses abrupt changes in contour, for the stress will be concentrated around the areas of maximum curvature. Scratches or other surface defects may produce a local reduction in the strength of the glasswork; any such fault is liable to be the origin of a fracture if the component is stressed.

The strains which can be induced in glass by thermal means can be classified into three categories, Permanent, Temporary and Differential. The three classes of strain may occur alone or in combination.

(i). *Permanent strains* are set up when glass cools quickly from a temperature in or above the annealing range. If a block of glass is heated uniformly to a temperature at which viscous flow can occur and is then allowed to cool in free air, the outer surfaces will cool more quickly than the inside and a temperature gradient will be established through the thickness of the glass. For simplicity, it may be assumed that no stresses will occur so long as some of the glass is within the annealing range of temperature.* When the hottest portion of the glass block has reached the lower annealing temperature, the outer layer will be at some temperature which is well below this value. The block will now consist of layers of solid glass which are cooling through different temperature ranges down to room temperature. The variation in the thermal contraction of the different layers will result in stresses between them, and the glass block will be in a strained condition. The strain is permanent, for it cannot be relieved by viscous flow because the temperature of the block at all points is now below the lower annealing temperature.

By the time the outer layers have reached room temperature, the inner layers still have to cool and since they are trying to contract while in contact with the rigid outer layers, it follows that when the block is uniformly at room temperature the inner layer will be in tension and the outer layers under compression.

The magnitude of the tensile and compression forces will depend on the temperature gradient and the coefficient of expansion of the glass. They may easily be made large enough to cause fracture.

It is therefore of fundamental importance that on the completion of any glass-working process, the glass should be cooled very slowly through the annealing range in order to avoid steep temperature gradients within the bulk of the glass. This slow cooling is known as the "annealing process."

(ii). *Temporary strains* occur when a temperature gradient is established in a glass body, the maximum temperature of which is kept below the annealing range. The strain cannot be relieved by viscous flow, but will disappear when the glass again assumes a uniform temperature.

Temporary strains occur during the heating of glassware preliminary to a working process and during the subsequent cooling schedule. The danger of fracture as a result of temporary strain is greatest when the glass has a high coefficient of expansion, and the temperature gradient is very steep. The steepness of the gradient is a direct function of the thickness of the glass and the rate of heating or cooling.

(iii). *Differential strains. Glass-Glass.*

If two blocks of glass of different thermal expansion are stuck together at one temperature and the temperature is then allowed to change, the different amounts of contraction or expansion in the two blocks will set up a stress at the interface. If, for example, the temperature of the joined blocks is increased, the glass with the higher expansion will be compressed at the interface and the glass with the lower expansion will be in tension. Differential strain is relieved if one of the component parts is within its annealing range. If the joint is made (as it normally is) at a temperature well above the higher of the two annealing ranges, it is obvious that it will be

* The argument employed here is strictly applicable to very thin adjacent layers of glass only. The conditions obtaining in a thick block should be derived by integrating the local stresses in an infinite number of pairs of adjacent thin layers interposed between the outer skin and the inside of the block.

stressed when cooled to room temperature, however carefully the cooling may be done. For freedom from fracture, the residual strain must be kept as low as possible. This imposes a limit to the permissible difference in expansion coefficients, which will depend upon the type of joint, and the thermal treatment to which it may be subjected.

In cylindrical butt-joints the margin of safety will be increased if the two glasses are very thoroughly fused together and the wall thickness of the joint kept down to about 0·5 mm. Thorough fusing causes some intermingling of the glasses and thus a more gradual change from one expansion coefficient to the other; and the flexibility of the glass is increased as the wall thickness is reduced. A joint made in this way between Pyrex and H.H. glass tubes is quite safe although the expansion difference is $1{\cdot}0 \times 10^{-6}$ per degree C.

Strains occur also in glass-metal combinations; these will be discussed in the section devoted to glass-metal joints.

C. Control in Glass Manufacture.

It has been shown that the three classes of strain, Permanent, Temporary and Differential are, to all intents and purposes, unavoidable.

The magnitude of the first two classes of strain can be kept within reasonable limits and the onus in this respect rests on the engineer in charge of the glass-working operation.

In the case of differential strain, however, the glass manufacturer must play his part also. The successful employment in industrial processes of glass-glass and glass-metal joints is only possible if the expansion coefficients of the component parts remain sensibly constant from sample to sample of raw material over long periods of time. The thermal expansion of metals can be controlled with ease to quite close limits, but the problem is more difficult in the case of glass. The thermal expansion is determined by the relative proportions of the ingredients and the thoroughness with which they are mixed and founded. Certain ingredients are lost by evaporation during founding and it is not easy to compensate for their loss with great accuracy.

However, by ensuring that the "batch" is carefully weighed and mixed and by keeping close control on the founding process, it is possible to achieve a limit to the variation in thermal expansion of about $\pm 0{\cdot}1 \times 10^{-6}$ per degree C. about a mean value. It is important to realise that this degree of control is necessary, especially in the more extreme cases of differential joints.

D. Choice of Glass.

Each and every kind of glass is produced for a specific purpose, and each application demands certain physical and chemical properties. From the point of view of the glass manufacturer, the essential requirements of a

TABLE 2.
Glass-Metal Combinations.

Metal		Glass		Colour of Cold Seal
Type	Coeff. of Expansion per Deg. C.	Type	Coeff. of Expansion per Deg. C.	
Tungsten	4.4×10^{-6}	Pyrex W.1	3.5×10^{-6} 3.9×10^{-6}	Light Brown to Straw
Molybdenum	5.5×10^{-6}	H.H.	4.5×10^{-6}	Dark to Light Brown
Platinum	8.9×10^{-6}	L.1 (Matched Seal) Almost all glasses if Platinum specially shaped	9.1×10^{-6}	Bright Metal
50% Nickel-iron ..	9.4×10^{-6}	L.1	9.1×10^{-6}	Medium to Light Grey
25% Chrome-iron ..	10.5×10^{-6}	X4 or X8	9.6×10^{-6}	Medium to Light Grey-Brown
Copper	16.7×10^{-6}	Almost any standard glass if metal specially shaped		Bright Red to Gold

commercial glass are that (i) it must be fluid enough to be melted at temperatures readily obtainable in large furnaces (say between 1400 degs. and 1500 degs. C.), (ii) it must be chemically stable and sufficiently viscous to avoid devitrification at low temperatures and (iii) it must possess a reasonable working range for the production of thin-walled bulbs and tubing.

The industries which subject fabricated glass to further processing require additional properties, such as controlled expansion, transparency and chemical durability.

The demand for a particular physical property is exemplified by the present trend in the design of certain classes of radio valve. In this development, the aim is to reduce the size of the envelope as much as possible without decreasing the wattage dissipation.

The manufacture and subsequent operation of such devices usually involves rapidly-changing temperatures which only a heat-resisting glass of low thermal expansion can withstand without fracture. This presupposes, of course, that suitable metals are available for making satisfactory joints.

2. GLASS-TO-METAL JOINTS.

A. Differential Strains. Glass-Metal.

A joint made by fusing glass to metal will not fracture if the residual stresses are well below the yield point of the glass. From first principles it would seem that the metal and glass should have identical thermal expansion over the range from room temperature to the annealing temperature of the glass.

In practice it is found that the most satisfactory "match" is obtained by so selecting the coefficient of expansion of the glass and metal that when the joint is cold, the glass in the vicinity of the metal is under slight compression.

Compression stress is preferable to tension or freedom from stress for two reasons.

(i). The breaking stress for glass when in compression is about ten times that for glass under tension.

(ii). In most devices where metallic conductors pass through the glass wall the temperature of the metal during a switching-on cycle increases more rapidly than that of the glass, either as a result of straightforward current loading or by conduction of heat from the electrode system within the device. In these circumstances the metal will expand temporarily if not permanently, more than the glass, and the glass will therefore be tension-stressed. If the glass is initially under compression when cold, then during a switching-on cycle it will first pass through a neutral or strain-free stage before developing tension-strain. It follows therefore that a glass to metal joint which is under slight compression when cold has a larger margin of safety than either strain-free or tension-strained joints.

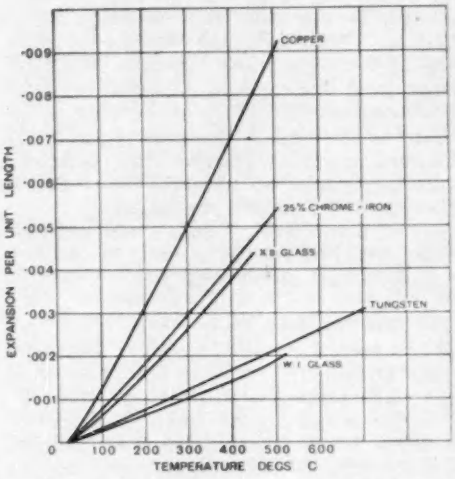

Fig. 1. Thermal expansion curves of glasses and metals.

Pure metals suitable for making matched seals are limited, by virtue of their physical or chemical properties, to the precious metals (in particular, platinum), tungsten and molybdenum. The scarcity has been met, to some extent, by the development of a range of alloys based on iron, nickel, cobalt and chromium. A well-known example is copper-plated nickel-iron alloy to replace platinum.

But glass to metal joints are not limited to "matched" combinations. If the stress in the joint can be made small enough by other means, the thermal expansions of the glass and metal need not be comparable. The necessary stress conditions can be met if the metal is sufficiently ductile to be distorted by stresses smaller in magnitude than the yield point of the glass. Copper, when suitably shaped, is a metal which fills this role admirably.

Copper in tube or disc form can be joined satisfactorily to glasses which range in thermal expansion from 10×10^{-6} to $3{\cdot}9 \times 10^{-6}$ per degree C., although the expansion coefficient of the metal is as high as $16{\cdot}7 \times 10^{-6}$ per degree C.

As with matched metal-glass seals, it is advisable to arrange that the residual stress in a cold copper-glass joint leaves the glass in compression.

Examples of matched combinations are given in Table 2, and typical expansion curves for glass and metal in fig. 1.

B. Selection of Metal.

It will be supposed that a glass-metal combination has been obtained which meets the required stress conditions. Further essential properties to be possessed by the metal are :—

(i). That its melting point should exceed by a reasonable margin the working range of the glass, or at least the lower limit of the working range.

(ii). That it should be available in quantity to a specified composition (or purity) and thermal expansion.

(iii). That the surface of the metal should be free from loose scale and score-marks.

(iv.) That the body of the metal should be free from splits, and in the case of copper-plated wires that the cross-sections should show a concentric sheath of copper.

The defects mentioned in (iii) may lead to the formation of bubbles on the surface of the metal during glassing, with a consequent reduction in the strength of the seal. Splits in the metal may provide leakage paths, while uneven plating of wires may result in a non-uniform distribution of stress in the surrounding glass which may lead to fracture.

C. Metal Oxides.

As most glass-to-metal sealing is carried out in free air at high temperatures, it follows that oxidation of the metal is difficult to avoid. Provided, however, that the oxide adheres strongly to the parent metal and does not impair the vacuum-tightness of the seal, there is no reason why special steps should be taken to avoid its formation.

In spite of its somewhat accidental origin, the oxide layer is sometimes a necessary part of the seal structure. Molten glass attacks some clean metals in such a manner that gases in solution in the molten glass are liberated.* The gas leads to the formation of minute bubbles at the glass-metal interface, thereby considerably reducing the strength of the joint. On the other hand, metal oxides are slowly soluble in molten glass and may thus serve as a cementing medium between the metal and the glass.

There are definite reasons why the thickness of the oxide should have upper and lower limits. Metal oxides are generally brittle and their thermal expansions differ considerably from those of the parent metals. Differential stress in a temperature cycle would therefore tend to free a thick oxide film from its metal.

On the facts given, all oxide films on metal joints should be as thin as possible, allowing only a sufficient margin of safety to ensure that the molten glass does not dissolve all the oxide during processing and so come directly into contact with clean metal.

Oxide films impart a distinctive colour to a glass-metal joint. The colour, which is characteristic of the metal, is apparent when the seal is cold but not while it is hot. In general the colour lightens as the oxide thickness is decreased. As the oxide thickness increases, a maximum depth of colour is attained which is unaffected by further increase in thickness. In practice the preferred oxide thickness is such that it falls well within the range which exhibits changes in colour, with a distinct bias towards the lighter shades.

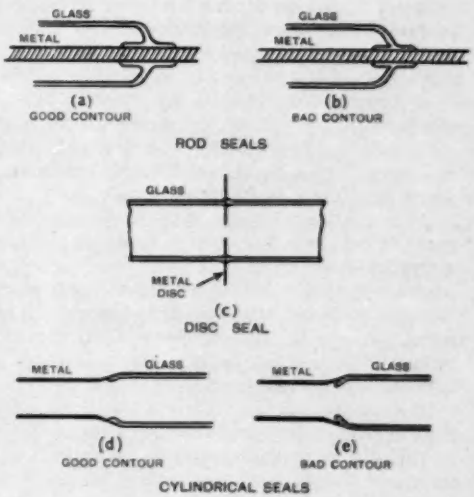

Fig. 2. Types of glass-metal joint.

Colour, then, is a definite guide in assessing the quality of a glass-to-metal joint. The permissible range of colour for a number of the better-known seals is given in Table 2.

* It is not generally realised that glass contains as much as its own volume of gas in solution. The gas is a mixture of the gases present in the glass furnace.

In view of the tendency to oxidise to excess, it is advisable whenever possible to sheath the metal with glass before the main sealing process is carried out, since by this means a more even standard of oxidation is obtained in the final product.

The rate of oxidation of the metal may be reduced by carrying out the sealing operation in an inert atmosphere, or by coating the metal with a temporary skin of fused borax through which oxygen permeates slowly. In the latter method, known as the borating process, the previously cleaned metal is slightly warmed, wetted with a saturated solution of borax, and then heated to redness to fuse the thin coating of borax thus acquired. This process is particularly necessary in the case of copper.

D. Types of Joint.

Joints made between glass and metal fall into three main types, rod, cylinder and disc, fig. 2. The portion of a round metal rod which is embedded in glass is essentially rigid and for this reason the glass and metal expansion coefficients must be closely matched. The rigidity, coupled with the wide difference in the thermal conductivity of glass and metal, renders the seal liable to fracture when subjected to thermal shock.

The cylindrical form invites special comment in that it is usually necessary to produce a feather edge on the extremity of the metal where the seal is to be made, and the metal has two surfaces available for glassing. This provision of flexibility is essential in the case of unmatched seals, and is desirable even in the case of matched seals.

The angle of the feather and the edge thickness may be varied within narrow limits to suit different glass-metal combinations and different degrees of mechanical strength in the metal member. Typical values are 3 degs. for the feather angle and 1 to 2 mils. for the edge thickness.

Disc seals may be matched or unmatched; in either case they should be treated with the same care as rod seals during any thermal process.

The stress in rod or cylindrical seals can be resolved into three components mutually at right angles; a longitudinal stress parallel to the axis of the rod or cylinder, a "circumferential" stress which is tangential to the periphery of the metal in a right cross-section and a radial stress perpendicular to the axis of the conductor.

If the metal has a higher thermal expansion than the glass, the residual stresses in a cold rod seal will be longitudinal and circumferential compression and radial tension.

Although tension strain in any form should be avoided, it is least dangerous if in the radial direction.

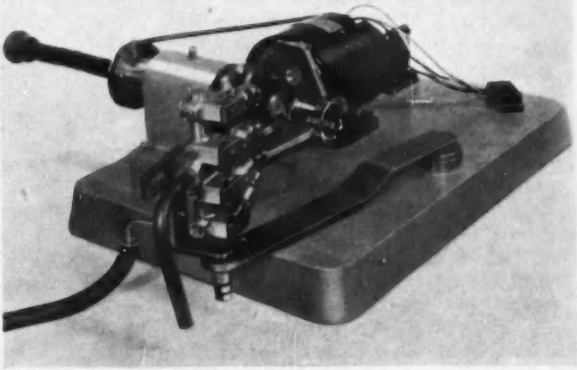

Fig. 3. Flanging machine fitted with wide-range three-jaw chuck.

If the same glass-metal combination is employed in a cylindrical seal, and the glass is fused to the external surface of the metal, the stress components will be of exactly the same sign as for the rod seal; but if the glass is attached to the inside surface of the metal the components of the residual stress in the cold seal will all be compressive.

Following the argument given in 2.A it is therefore preferable to glass a cylindrical metal conductor on the inside. However, no harm will arise if the metal edge is glassed on both faces; indeed, the protection of the feather edge by this means from mechanical injury or high voltage flashover is often desirable.

To avoid a reduction in the bore of a cylindrical conductor by the presence of glass on the inner surface, the feathered end may be flared outwards. The flare angle has little effect on the magnitude of the stresses provided it is kept reasonably small.

E. Contour of Glass.

For reasons given in 1.B the shape of a completed seal should show no sharp or

re-entrant angles. Examples of good and bad seals are shown in fig. 2.

The presence of sharp angles in a glass-metal joint indicates that the glass at the apex of the angle has not been heated sufficiently to secure thorough fusion. In technical parlance, the seal is "cold-worked." The soundness of the joint is thereby impaired and cracks are liable to develop in the angle, even if the local stresses are not high.

In rod seals, the desired shape is more easily obtained if the rod is sheathed with glass before the main seal is completed. The provision of a flat circular button on the sheathing is of great assistance when sealing a rod into the end of a glass tube.

In cylindrical seals the fused edge of the glass should be as nearly as possible perpendicular to the metal surface at the point of contact.

If the feather edge is completely enclosed in glass the depth of the external seal should not exceed the depth of the internal seal, for the overlapping glass will be in radial tension. This is particularly important in the case of copper-glass seals.

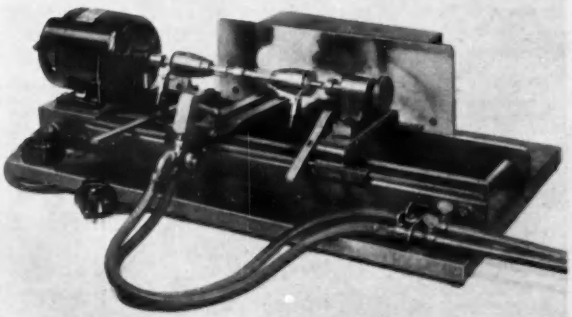

Fig. 4. Machine for making small glass-metal butt-joints.

3. THE DESIGN OF GLASS WORKING MACHINERY.

A. Rotating Machines.

The greater proportion of the glass-working processes employed in the lamp and radio valve industries are carried out on cylindrical bulbs or tubing.

For the reasons given in 1.B any heating process must be so performed that temporary or permanent stress is kept within reasonable limits. This condition can be realised in all processes by a sufficient prolongation of the heating and cooling cycles, but this method is far from being economical in time or thermal energy. A satisfactory compromise between speed of operation and loss due to fracture may be achieved if the circumferential temperature distribution at any instant is kept within close limits.

One method of securing uniform heating is to surround the glass member with a heating device which supplies energy equally along all radii; but a more practical device is to rotate the glass member relative to a narrow heating zone. Thus the glass may be rotated at uniform speed about its longitudinal axis in a fixed flame or the flame may be rotated about the axis of the glass which may then be stationary. For reasons to be given later the former alternative is to be preferred. Most glass-working machinery can thus be characterized by the need to rotate glass members at reasonably uniform speeds. The complexity of design will depend upon the process to be performed, and should be determined by careful consideration of the following points.

(i). *Relative motion of glass and flame.*

The rotating flame technique should be avoided where possible because it involves the use of leak-proof rotating gas-valves, and the control of temperature by the critical adjustment of burning gases. In the rotating-glass method of operation the flame can be pre-set and the rate of application of heat to the glassware controlled by varying the area of contact between the flame and the glass.

In many processes the glass is tooled into shape while in the plastic shape. The tooling process is performed much more easily when the glass rotates than when the tool rotates. In practice the rotating flame method is employed only when the finished product demands the utmost precision, and no alternative process is available.

(ii). *Speed of Rotation.*

Glass within the working range of temperature is sufficiently mobile to be distorted by gravity. Thus if a glass tube, held horizontally by one end, is heated strongly at the other end, the molten glass will sag. On the other hand, if the glass is rotated about its axis at high speed its mobility at high temperatures will cause it to be flung out radially by centrifugal force. For ordinary processing, the

speed of rotation is adjusted so that the centrifugal force just balances the natural tendency to sag and the glass maintains its shape even though quite plastic. The speed is fairly critical and will depend upon the diameter of the glass tube.

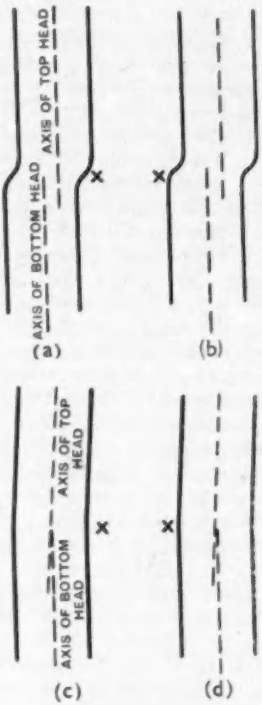

Fig. 5. Effect of misalignment in double-head machines. Parallel displacement: (a) and (b) show the seal at two stages spaced 180° apart. Note that the shape of the seal at point X undergoes complete reversal. Angular displacement: (c) and (d) show the seal at two stages spaced 180° apart. Note that the seal at point X is first compressed and then stretched.

In some processes the centrifugal distortion of glass is employed to replace a blowing or tooling operation, in which case the machine should be provided with means for the rapid change from one speed to another. The change in speed can be effected electrically (with D.C. motors) or mechanically.

(iii). *Single unit processing.*

If the processing is carried out on a single piece of glass, the machine need consist of one rotating head only. Single head machines are used for simple processes such as the flanging of one end of a glass tube. Fig. 3 illustrates a typical flanging machine.

(iv). *Twin-unit processing.*

The sealing together of two glass components or the making of a glass-metal joint calls for a machine which has, in effect, two heads.

This class of machine may take one of three forms.

(*a*) *Single-head drive. Rigid coupling.*

In this machine the two components are to be held in separate holders or chucks, but the chucks are rigidly connected and rotate as one body. This type of machine is usually of simple design and easy to construct; but the members which hold the two chucks together must cross in front of the flames during rotation, and are liable to disturb the uniform heating of the glass.

Machines of this type were used at one time for sealing pinches into lamps and radio valves by the drop-seal method.

(*b*) *Single-head drive. Flexible coupling.*

When the two components require to be moved relative to each other along their common axis, the coupling between the chucks must be flexible. A simple way in which this may be arranged is to provide the chucks with keys which slide in a groove in a common shaft. The keys transmit the drive and the components may be moved by means of levers engaging in peripheral slots in the chucks. (See fig. 4).

Naturally this technique can be used only if the component parts will accommodate an internal shaft. A further point to be borne in mind is that the shaft will in all probability become heated during the process. Provision must therefore be made to accommodate the expansion of the shaft (*e.g.*, by means of a spring-loaded tail-stock), and the shaft should be of heat-resisting material and quite straight. (See next section on misalignment).

This type of machine is used extensively in the manufacture of cylindrical glass-metal seals.

(*c*) *Double-head drive.*

As indicated in the previous section, some articles will not admit the use of an internal driving shaft. The chucks must then be driven externally and, if movement is required, the chucks are usually mounted in independent heads with a common lay-shaft drive. Chain or gear transmission is quite satisfactory.

Having separated the two driving heads it is imperative that they be accurately in axial alignment. Misalignment, whether it be from parallel or angular displacement,

may render a machine completely useless for glass-working operations. If two pieces of glass are fused together in a badly aligned machine, each part of the joint will be alternately stretched and compressed once in each revolution. This "knitting" action will affect the quality of the plastic seal, but, what is more important, the mechanical stresses set up when the glass becomes solid will almost certainly cause fracture. (See fig. 5).

A good example of a double-head drive machine is shown in fig. 6, which illustrates a large universal glass lathe. The prototype machine was designed and constructed some 20 years ago at the G.E.C. Research Laboratories for the manufacture of large transmitting valves. The lathe is 8ft. long overall and will accommodate work up to 10 inches in diameter. The photograph shows one of the chucks holding an 8 inch diameter glass-metal joint. Each head is chain-driven from a grooved line-shaft running the whole length of the machine, and can be moved independently at fast or slow speed along the bed of the machine. The basic speed can be varied with a potentiometer-controlled D.C. motor, and the drive is taken through a pedal-operated two speed gear box (ratio 10 : 1). The bed of the machine can be held at any angle between the horizontal and the vertical.

B. Glass-holding Chucks.

The successful mechanization of glass-working processes is to a large extent dependent upon the provision of suitable chucks to hold the glass members.

Glass tubing or mould-blown bulbs cannot be produced economically to very close dimensional tolerances. To the glass manufacturers, a spread in tubing diameter of $\pm$ 5 per cent about a mean value represents a high standard of production ; closer limits will mean that a correspondingly higher proportion of the production must be scrapped. Additional variations will occur in the wall thickness of the bulb or tube, both longitudinally and circumferentially in any one sample and from sample to sample. Furthermore, a slight degree of longitudinal taper and ovality in cross-section must be expected and allowed for. All glass chucks should be designed to accommodate these variations, particularly the spread in internal or external diameter.

The action of the chuck may be positive or spring-loaded. With positive action, care should be taken to avoid mechanical distortion and fracture of the glass by unequal distribution of the retaining forces ; the development of local high stresses may be prevented by the use of resilient pads at the points of location.

In any type of chuck, the points of location should be kept well away from the cut ends of a tube or bulb for there the glass is in its weakest state.

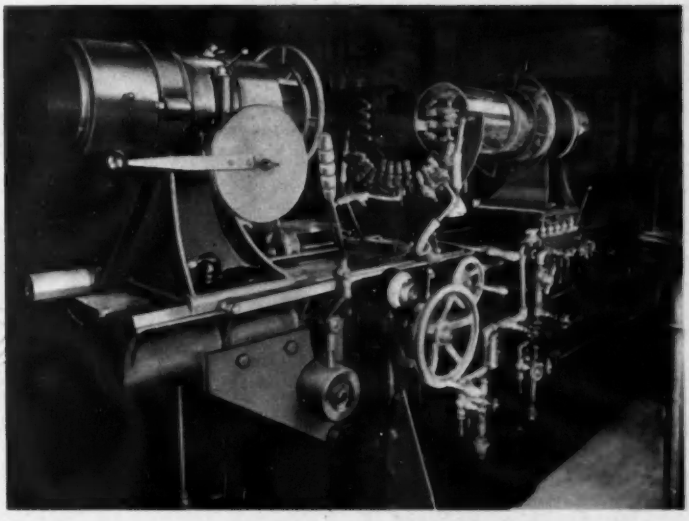

Fig. 6. Universal glass lathe.

In many cases the chuck will have to operate at reasonably high temperatures; the spring-loaded chuck should, therefore, have the spring remote from the source of heat and made of heat-resistant material.

It should be remembered that glass is both very hard and very brittle (some breakage is bound to occur); the general design of the chuck should, therefore, allow for wear and tear and the ready removal of broken glass. Protruding parts should be avoided, and if the chuck is to be used at high rotational speeds its weight should be properly balanced. The merits of various types of chuck will now be considered.

(i). *Spring chucks.* These are usually made from an appropriate grade of steel tubing which has been split longitudinally at several places. The tubing can be shaped to provide two-point location, or the split tube may be associated with a conical centring piece at one end. Spring chucks may hold the glass internally or externally; they will not accommodate much variation in diameter and are liable to take a "set" at high temperatures.

(ii). *Three-jaw chucks.* A good example of a three-jaw, spring-loaded, self-centring chuck is illustrated in fig. 3. This particular model will accommodate tubing varying in size from 50 mm. to 10 mm. diameter.

A positive action chuck on similar lines can be made from the ordinary metal-working 3-jaw chuck. Internal or external location is possible.

(iii). *Four-jaw chucks.* If the glass bulb or tubing is very heavy or oval in cross-section, the chuck should be based on the design of the metal-working 4-jaw chuck. In its simplest form, the chuck may consist of a suitable metal tube or strip framework carrying a number of set screws. A version of the "bell-chuck," as it is called, is shown fitted to the lathe in fig. 6.

(iv). *Three-vane chuck.* The radial movement of the 3-jaw chuck may be replaced by the angular movement of three members or vanes, linked together and operated by one compression spring. An example of this form is shown in fig. 7(a). The principle may be used in both internal and external chucks.

(v). *Ball and cone chuck.* Fig. 7(b) illustrates a device in which the effective diameter of the chuck is varied by sliding three steel balls up and down a conical surface. There are two such units per chuck and the action of the whole is controlled by one spring. This type of chuck, in both the internal or external form, is very accurate and reliable.

(vi). *Collet chuck.* A spring-loaded collet chuck is shown in fig 7(c). The throat diameter is varied by sliding three jaws up and down a conical surface. The chuck is suitable for small variations in tube diameter and has a smooth exterior; but it is liable to become fouled by broken glass.

(vii). *Vacuum chucks.* If a glass bulb has a flat end the most convenient way to hold it for rotation about its longitudinal axis is by means of a vacuum chuck.

The device is often used in the processing of cathode ray bulbs and consists of a metal tube, machined true at one end and connected to an exhaust pump at the other. The bulb is held securely against the machined end (through a suitable resilient packing) by virtue of the pressure difference so established. The diameter of the chuck is determined by the weight of the bulb.

(viii). *Dimpled tubes.* In some electronic devices the electrode system is required to be located with great accuracy off the inner wall of the glass tube. To do this the tube is first dimpled inwards at several points to make contact with an accurately machined internal mandrel. (The tube is heated locally and pressed into shape with a simple tool). By careful selection of the mandrel diameter and control of its temperature the effective bore of the dimpled tube can be held to

(a) (b) (c)

Fig. 7. Three forms of chuck to hold glass tubing.

within a few mils. of a mean value. The tube having been thus pre-shaped, a chuck for subsequent processing may consist of a rigid cylindrical member of appropriate diameter. Radial location is assured, but the longitudinal grip will not be good.

C. Glass Cutters.

All glass tubing and most bulbs have to be cut to length at some stage in processing. In general the cut must be made in a plane perpendicular to the axis of the tube. The following methods may be employed.

(i). *Flame cutting.*

The tube or bulb is heated very strongly over a narrow band and parted off by pulling and so breaking the ring of very fluid glass. The objections to this method are that it calls for considerable skill on the part of the operator and may leave the glass end irregular in thickness.

(ii). *Hot-wire method.*

The glass is scratched around the circumference with a hardened steel knife or file. A nichrome wire is wrapped round the scratch and heated electrically to about 750 degs. C. This method of heating induces intense stresses in the glass in the neighbourhood of the scratch where the glass is weakest, and the glass cracks through quite cleanly.

(iii). *Wheel cutters.*

Glass tube may also be cut, or rather sawn, with the aid of thin cutting wheels impregnated with carborundum or diamond chips. The wheels rotate at high speed and are liquid-cooled. The mechanical shock associated with cutting may cause the glass to fracture during the last stages.

An alternative cutting wheel is made from thin hardened steel, rotating at a very high speed. The glass tube is pressed against the edge of the wheel and rotated at the same time. The action of the wheel is first to scratch the glass and then to shock it thermally by virtue of the intense frictional heat developed. Some contamination of the glass by the cutting wheel may occur.

(iv). *Diamond cutters.*

The quickest method of cutting glass tube is to make an internal circumferential cut (as distinct from a scratch) with a diamond and complete the fracture by thermal shock. The cuts thus obtained are of excellent quality, and are clean and accurately located. The method is dependent for its success upon the careful setting of the diamond cutting point relative to the glass wall and upon the life of the diamond. Life failure is caused by mechanical breakdown of the cutting point and not by abrasive action. Diamonds vary very considerably in life and the necessary provision of spares is rather costly.

D. Burners and Torches.

The most convenient way in which to heat glass during processing is by means of gas-

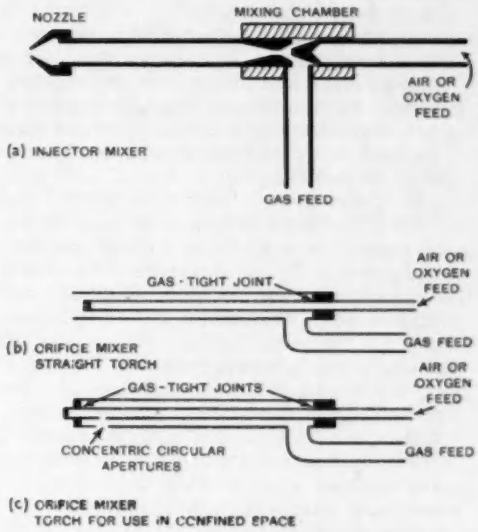

Fig. 8. Injector and orifice mixers for gas-air and gas-oxygen torches.

flames. The combustible gas is usually coal-gas, mixed with air or oxygen. For the working of silica glasses, additional heat is obtained by using oxygen-hydrogen or oxygen-acetylene mixtures. The mixing of the two gases occurs either in an injector-type mixing chamber or at an orifice.

(i). *Injector mixers.*

As shown in fig. 8(a) the air or oxygen, which should always be at a higher line-pressure than the coal-gas, emerges from a jet into a conical housing connected to the gas supply. A partial vacuum is created in this housing and the coal-gas is thereby drawn into the main stream. The mixed gases travel along a pipe and burn at the nozzle attached to its end. There are two common troubles with this type of burner, "back-firing" and "blowing-back." A "back-fire" is an explosion of the mixed gases inside the burner and can be avoided

by maintaining a sufficiently high rate of feed of mixed gases to the burner nozzle. A "blow-back," whereby air (or oxygen) is forced down the gas feed-pipe, is the result of a build-up in pressure within the burner. The build-up will not occur if the mixer orifice is considerably smaller than the nozzle orifice.

To avoid the possibility of a serious explosion in the gas line from this cause, a non-return valve should always be installed in the gas feed-pipe.

Torches with injector mixers are quite robust and of simple construction. They may be made up into ring and strip burners merely by provision of the requisite number and distribution of nozzles. They are ideal for use in restricted spaces.

(ii). *Orifice mixers.*

Two forms are shown in figs. 8(b) and 8(c). The basic principle is that the air or oxygen emerges from a small orifice at high velocity into an atmosphere of coal-gas. The burning gas is thus supplied with oxygen from the inside and the thermal efficiency is quite high.

Orifice-type burners cannot "back-fire" or "blow back," provided all internal joints are gas-tight. Since it operates with a high velocity oxygen stream, the flame of an orifice burner can exert a fair pressure on any interposed surface. This property has been used sometimes to force glass in a preferred direction.

E. Annealing Lehrs.

Most glass-houses are fitted with "lehrs," or machines which carry fabricated glass articles through the annealing range of temperatures at slow speed. They are usually fitted with moving belts, are gas, oil or electrically fired, and are of generous proportions. A full discussion of lehr design is outside the scope of this paper, but it is worth while to describe two simple forms which may be usefully employed for the annealing of mass-produced small glass components.

(i). *Continuous Belt Lehr.*

For the annealing of soft glass pinches the following design has proved quite successful.

The lehr proper consists of a 6 foot length of 4 inch diameter, heavy-wall brass tube. One half of the tube is heated uniformly with a special long gas-air burner, the heat insulation being obtained with thin aluminium foil. This section is maintained at the upper annealing temperature of the glass. The other half is allowed to radiate freely in the open air; the rate of fall of temperature along this section is found to be sufficiently slow to avoid excessive temporary strains, and the take-off temperature is low enough for ordinary handling. Through the brass tube, over pulley-wheels at both ends, runs a continuous belt, 3 inches wide, of reinforced woven asbestos. A drive is connected to one of the pulleys so that the rate of movement of the belt is about 2·5 inches per minute. It was found necessary to close the hot end of the brass tube as effectively as possible with a hinged door to avoid convection draughts inside.

Fig. 9. Disc sealing machine.

The success of this design lies in the use of the heavy-walled brass tube; the heat content of the hot zone is great enough to smooth out any violent temperature fluctuations which may result from variations in the gas supply to the burner, and the thermal conductivity of the tube is sufficiently high to establish a reasonable temperature gradient in the cooling zone.

(ii). *Rotary Lehr.*

A satisfactory lehr which can be loaded and unloaded by one operator takes the form of an incomplete circular tunnel. The tunnel, of rectangular section, has a narrow aperture at the bottom, and forms two-thirds of a circle. The remaining third is an open space for loading and unloading.

The lehr is arranged to be coaxial with, and fixed just above, a horizontal circular turntable which carries a number of pegs spaced around the edge. The articles to be annealed are hung on the pegs which travel through the tunnel by way of the bottom slot.

The tunnel is heated electrically and is thermally insulated with aluminium foil.

The articles enter in a hot zone maintained at the annealing temperature and then pass through a cooling zone. Again it was found necessary to close the hot end with a door to restrict convection draughts. The turntable is rotated by hand and the annealing schedule occupies about 30 minutes.

4. MECHANIZED GLASS-WORKING PROCESSES.

The number of mechanized glass-working processes is legion, but in reality they involve only a few fundamental operations, viz :—

A. *Butt-joining* of tubes of similar diameter, including glass-metal seals.

B. *Drop-sealing*, or the coaxial joining of tubes of different diameter.

C. *Side-stemming*, or the joining of tubes of different diameter perpendicular to each other.

D. *Forming*, or the local alteration in the diameter of a tube or rod.

These operations will be considered in turn.

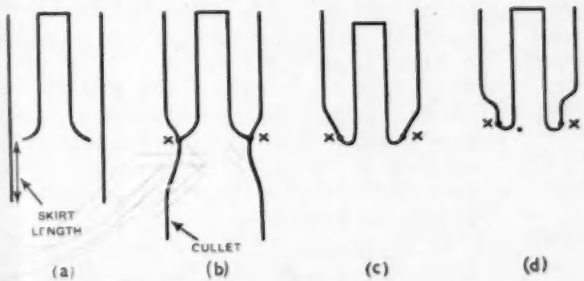

Fig. 10. Stages in the making of drop-seals.

(a) Tubes arranged coaxially, with correct skirt length.
(b) Outer tube shrinks in diameter and is extended. First contact made at X—X ; cullet ready to be cut off.
(c) Inner tube lowered. Joint now occupies position X—X.
(d) Alternatively to (c) the outer tube is tooled and joint occupies position X—X.

A. Butt-joining.

The joining of two tubes in line requires the use of a lathe in which the holding chucks may be moved relative to each other along their common axis. The adjacent ends are heated locally to the working temperature and then brought into contact and thoroughly fused together. The immediate result is to thicken the glass in the neighbourhood of the joint. The art in butt-joining is to redistribute this glass so that the finished joint has a uniform wall thickness. The result can be achieved by a judicious combination of centrifuging, tooling and stretching. Centrifuging will cause the diameter of the molten glass to increase ; tooling, which means the working of molten glass with a relatively cold metal rod or bar usually involves a reduction in diameter. A typical application of the butt-joining process is to be found in the glass-metal seal.

Fig. 4 shows a machine ready loaded for joining glass to both ends of a flared copper tube.

For internal seals the glass is first tooled down to a diameter less than that of the copper flare, heated to a high temperature and centrifuged on to the inside surface of the metal. External seals are made by tooling the glass down on to the outer surface of the flare and inside-outside seals by a combination of both processes.

The driving head for the shaft, and the levers which transmit lateral motion to the chucks are clearly shown in the photograph. Fig. 9 illustrates the procedure for making a disc-type glass-metal seal. This is a version of the butt-joint which does not require high-speed manipulation.

B. Drop-sealing.

The two tubes to be joined may be arranged head-to-head or one within the other. They are held with their common axis vertical and the working end of the smaller tube must be flared previously to a diameter which is a few millimetres less than the bore of the larger tube. The type of machine to be used will depend upon the need for relative longitudinal movement of the two members ; that shown in fig. 9 is often used. The stages in the process are shown in figs. 10(a) to 10(d).

The outer tube is heated over a narrow band in the neighbourhood of the flare. The rate of in-

crease of temperature to the working range is limited by the wall thickness. When the glass is molten the weight of the skirt or cullet will tend to stretch the outer tube, while surface tension will cause a local reduction in diameter. The outer glass will then make contact with the flare; the cullet is cut off with a flame and the joint well fused. There will invariably be a thickening at the joint. It is inadvisable to have an abrupt change in wall thickness at the point of maximum curvature so the joint is usually transposed towards the parallel portion of the outer tube. This can be done either by pulling the two members apart slightly or by tooling the outer glass. An additional reason for tooling is that it provides a seating for any subsequent capping process.

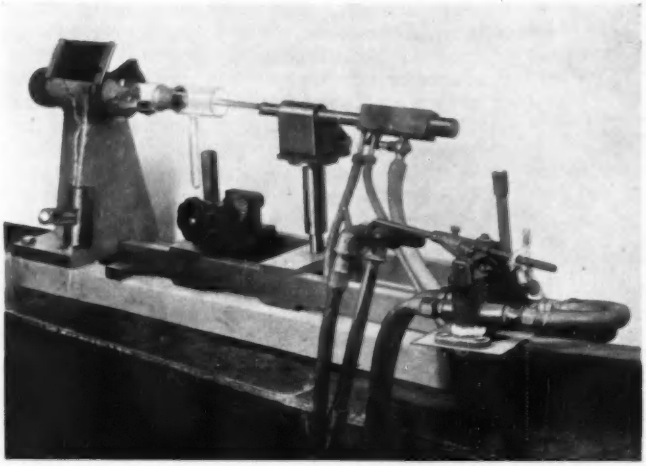

Fig. 11. Side-stemming machine.

A drop-seal requires fairly careful annealing; the point to be remembered is that the whole of the contour (and not merely the outer portions) should be heated to the upper annealing temperature and then cooled equally through the annealing range.

The machine speed is always low—about 60 r.p.m.

C. Side-stemming.

The method used by a glass-worker in making a side-stem or "T" piece is to heat the main tube locally to the working temperature and make a hole (by blowing inside the tube) of a diameter comparable with the stem. The stem is butted against the hole and the joint thoroughly fused. A good shape is obtained by appropriate blowing, pulling and pushing. The skill required to make the joint is not inconsiderable.

The machine process for side-stemming is radically different in procedure and requires little skill. A suitable machine is shown in fig. 11.

The main tube is held horizontally in a chuck which can be rotated by hand or power-driven. The stem is held vertically in a simple grip immediately below the axis of the main tube, and can be moved up and down by means of a rack and pinion. The stem must be closed at the lower end. The stages in the process are shown in figs.12(a) to 12(d).

The main tube is rotated and heated with a gas-air torch in the region where the joint is to be made. When it has assumed a temperature in the annealing range the main tube is stopped in the correct position for stemming. A special oxy-coal gas burner of the type shown in fig. 8(c) is now inserted into the main tube and the glass wall heated strongly immediately above the open end of the stem. When the wall is molten the stem is raised to make contact with it. Further heating thoroughly seals the two members together and the air pressure inside the stem (now closed at both ends) is increased sufficiently by the heating to cause a hole to be blown in the molten wall of the main tube. The molten glass is uniformly distributed by a short further heating in which the pressure of the flame plays an important part. The oxy-coal gas burner is then removed and the wall thickness in the region of the joint made even by pulling the stem downwards by a small amount. When the glass has solidified the stem is released from its grip and the joint annealed by rotating the finished article in a gas-air flame.

From the manner in which the process is carried out, it is clear that the possibility of the joint being leaky is very remote. The shape and quality of the joint are up to the highest standards of bench-workmanship.

D. Forming.

An example of the forming of a tube has already been given in the final tooling to shape of a drop-seal. The forming of a glass rod, or its equivalent, occurs in the preparation of a "button" on a metallic conductor. Fig. 13 shows a machine adapted for the purpose.

The conductor (in this case a heavy tungsten rod) is held horizontally between a driving head and a freely rotating tail-stock. The head and tail-stock must be thermally insulated from the rod. A piece of thick-walled W.1 glass is slipped over the tungsten and fused into position while the rod rotates at slow speed. When thoroughly molten, the bulk of the glass is scraped inwards from both ends with the aid of a pair of tools which operate scissor-fashion. The final result is a flat button of circular cross-section set in the middle of a length of thin sheathing. The tungsten wire, so prepared, is now ready for sealing into the end of a tube by the drop-seal, or any other convenient method.

5. FUTURE DEVELOPMENTS.

It is unwise to be prophetic. In this short discussion mention will be made only of new processes which show promise.

A. Precision Devices.

The trend in the design of some types of radio-valve is towards a greater use of metal (particularly copper) in the envelope. At the same time the performance characteristics of valves are becoming more and more dependent for their uniformity and stability upon the ability to set and hold small inter-electrode clearances to within close limits. From these facts it is clear that considerable developments are to be expected in the sealing of glass to metal, and in the provision of glass-working machinery of adequate precision.

B. Pressed Glassware.

There are many glass components used in the lamp and radio-valve industries which can be made only with difficulty from the usual raw materials—tubing, bulbs and rod. Quite often the article can be produced more readily by pressing a molten mass of glass into a suitably shaped die. Pressed glass parts are relatively cheap (when produced in quantity) and have the great advantage that they can be made to conform to close dimensional tolerances.

Pressed bases, in which are sealed a number of metallic conductors, are already replacing or supplementing the more familiar tubular pinch.

The window end of the bulb used for cathode ray tubes must have good light transmission properties and adequate strength to withstand the atmospheric pressure. Pressed ends, in which the glass thickness at all points can be pre-set accurately, are well suited for the purpose.

C. Heating Devices.

In some applications of the glass-metal technique it is desirable to distort the glass member as little as possible. If the fusing process can be carried out by supplying direct heat to the metal only, the requirement is

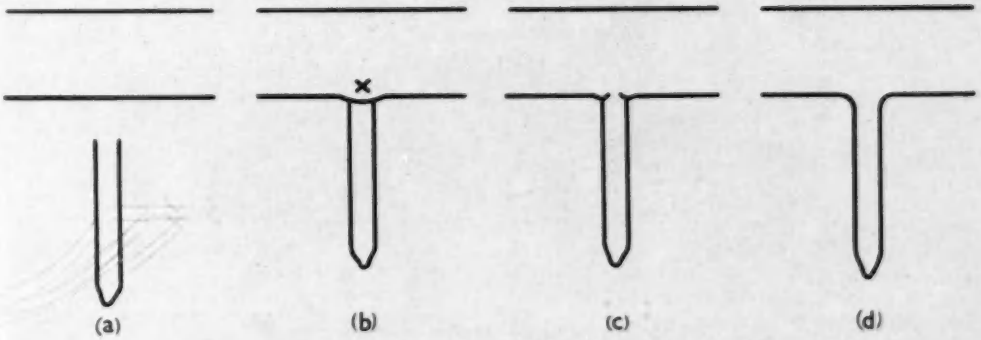

Fig. 12. Stages in the side-stemming process.

(a) Initial arrangement of main tube and stem.
(b) Main tube softened at X and stem raised to make contact.
(c) Joint thoroughly fused. Hole blown automatically in wall of main tube.
(d) Joint shaped with flame. Stem pulled down slightly.

fulfilled. An eddy current heater could be used for the purpose provided the metal is of suitable shape for loose-coupling to the generator inductance coil.

High-frequency electric currents have also been ingeniously employed for the local heating of all-glass articles. Although glass is usually regarded as a good electrical insulator, its electrical conductivity increases rapidly with temperature.

For example, glass may be maintained in the molten state by passing an electric current through it. In addition the gases in a flame are ionized, and may provide a conducting path through space. It follows that if a piece of glass is heated to a reasonably high temperature with two opposed torches, and the high frequency supply is connected between the torch nozzles, the hot glass will form part of the electrical circuit and will therefore receive additional heat by the passage of current.

D. Training of Technical Assistants.

There will always be work demanding the manipulative skill of the orthodox glass-worker, but there is a growing volume of production in the planning and execution of which something more than craftsmanship is required.

The training of suitable men, who may be described as "technical glass-workers," should cover three subjects in the following order :

(i). A good grounding in engineering drawing and design and workshop practices.

(ii). The physical and chemical properties of glass. The old days have gone when the breakage of glassware could be attributed, in all seriousness, to bad luck. If a glass article develops a fracture, there is a very good reason why it does so. In finding that reason the knowledge gained may prove to be of manifold application.

(iii). The manipulation of glass. A thorough appreciation of the working properties of glass is an invaluable aid in designing machine processes.

Although most glass-blowers are apprenticed to the trade on leaving school, there is no reason why an enterprising glass-worker should not reverse the training order given above in order to increase his sphere of usefulness.

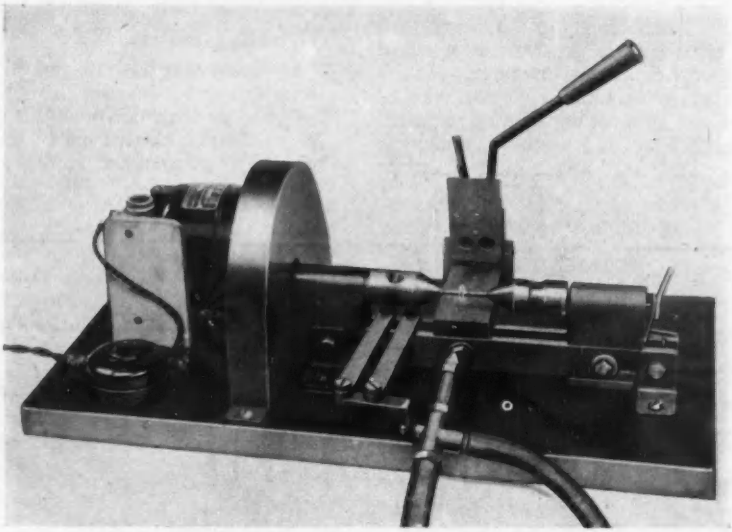

Fig. 13. Machine for shaping glass buttons on metal rods.

Parallel Running of Direct Current Generators.

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INTRODUCTORY.

MANY papers have been written on the parallel running of compound wound generators, but in very few has there been any attempt to evolve a rational procedure for arriving at the resistance of the equalising connection.[1] It is usually considered sufficient to state that the resistance of the equalising connection should be low compared with the resistance of the series winding. In normal circumstances this condition is easily fulfilled and no trouble is experienced with generators properly designed for parallel running. Occasionally trouble occurs and when investigated is usually found to be due to the equalising cable being very long and the resistance correspondingly high. In such circumstances the resistance of the equaliser must be reduced, either by reducing the length or increasing the section. Where the station layout is such that the length cannot be reduced the section must be increased, the usual procedure being to increase the section of the equalising cable until its resistance is low compared with the resistance of the series windings. Long lengths of heavy cable are expensive and in such circumstances it is useful to have some logical method of determining the smallest size of cable which can be used and thus reduce the cost to a minimum, while ensuring satisfactory operation. Any economy which can be effected in material or labour in this way is particularly valuable in the present circumstances, and it is hoped that this can be done by using the results developed in this paper.

The paper is divided into three parts. The first part is on the parallel running of shunt dynamos and states the conditions which must be fulfilled for satisfactory operation. The second part is a graphical analysis of the parallel operation of two identical compound wound dynamos designed for an output of 9·2 kW. The conditions for satisfactory parallel running are deduced by comparing them with shunt dynamos. The third part is a mathematical analysis of the parallel operation of two identical compound wound generators. A formula is evolved for determining the permissible resistance of the equalising cable from the data normally available to the machine designer. From this formula, curves have been calculated from which the resistance of the equaliser can be quickly determined for any size of machine.

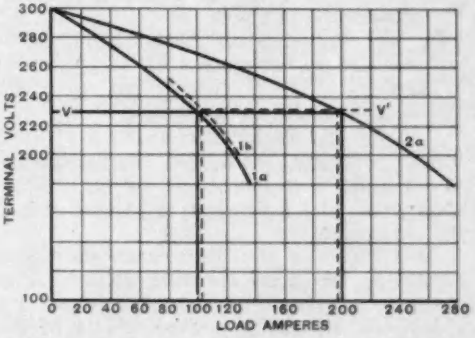

Fig. 1.—Parallel operation of shunt wound generators with a large voltage drop from no load to full load.

SHUNT DYNAMOS IN PARALLEL.

Shunt wound dynamos with drooping load characteristics generally work quite well in parallel. That this should be so can be seen by considering fig. 1. Curves 1a and 2a are the external characteristics of two shunt wound generators operating with their shunt regulators set for equal no-load voltages. If these two generators are placed close together and are operating in parallel to supply the total load on the station, then the total current will divide between the two machines in such a way that the terminal voltages of the two machines will each be equal to V. The corresponding load currents will be I_{a1} and I_{a2} the shunt

circuits being considered as part of the load. If the speed of the engine driving machine 1 increases slightly, the external characteristic of this machine will change from curve 1a (solid) to curve 1b (dotted). Under these new conditions the load currents of the two generators cannot remain at I_{a1} and I_{a2} because if they do the terminal volts of machine 1 will increase, and there will be a difference of voltage between the two machines. As soon as this voltage difference comes into existence it causes a current to flow from machine 1 to machine 2 so that the current flowing in the armature of machine 1 increases and the current flowing in the armature of machine 2 decreases. This current and its rate of change are such that the terminal voltages of the two machines are restored to equality at a value slightly higher than the original voltage V.

Now let V represent the terminal voltage of the two generators before the disturbance takes place:

E_1 and E_2 represent the internal e.m.f.'s of the two generators.

I_{a1} and I_{a2} represent the armature currents of the two generators.

R_{a1} and R_{a2} represent the armature resistances of the two generators.

Then

$V = E_1 - I_{a1} R_{a1}$ for machine 1.

$V = E_2 - I_{a2} R_{a2}$ for machine 2.

For machines with the characteristics shown in fig. 1 an increase in current will be accompanied by a decrease in internal e.m.f. and vice versa.

As a result of the disturbance additional e.m.f.'s appear in the armature circuits. The generated e.m.f. of machine 1 increases by $\triangle E_1$, due to the combined effects of the initial disturbance and the increase $\triangle I_a$ in armature current, and as the armature current is changing an e.m.f. of self induction $\triangle E_1'$ appears in the armature, so that for machine 1 the e.m.f. equation becomes

$$V + \triangle V = E_1 + \triangle E_1 - (I_{a1} + \triangle I_a) R_{a1} - \triangle E_1'$$

In machine 2 there will be an increase $\triangle E_2$ in the generated e.m.f. due to the decrease $\triangle I_a$ in the armature current, and there will also be the e.m.f. of self induction $\triangle E_2'$ opposing the reduction in the current so that the e.m.f. equation for this machine becomes

$$V + \triangle V = E_2 + \triangle E_2 - (I_{a2} - \triangle I_a) R_{a2} + \triangle E_2'$$

From these equations it follows immediately that

$$\triangle E_1 - \triangle E_2 = (R_{a1} + R_{a2}) \triangle I_a + (\triangle E_1' + \triangle E_2')$$

so that the difference in the internal e.m.f.'s of the machines is absorbed partly by the volt drop due to the resistance of the circuit and partly by the e.m.f. of self induction appearing in the circuit. The current $\triangle I_a$ will continue to increase until the volt drop in the resistance due to $\triangle I_a$ is equal to the difference in the internal e.m.f.'s This increase in current will be small for the case illustrated in fig. 1 because as I_{a1} increases

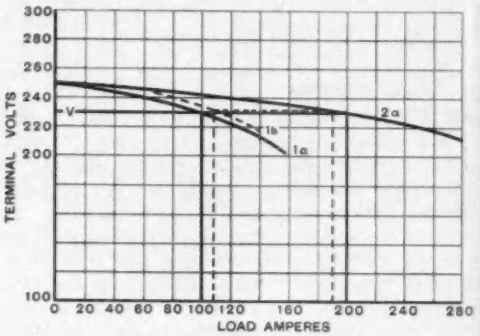

Fig. 2.—Parallel operation of shunt wound generators with a small voltage drop from no load to full load.

and I_{a2} decreases $\triangle E_1$ decreases and $\triangle E_2$ increases and the difference $\triangle E_1 - \triangle E_2$ decreases rapidly. When equilibrium is established

$$\triangle E_1 - \triangle E_2 = (R_{a1} + R_{a2}) \triangle I_a$$

The steady state terminal voltages settle down to equality at a value slightly higher than their initial value and there is only a small change in the currents. This equation shows that the value of $\triangle I_a$ depends on two things; the change of internal e.m.f. with current and the internal resistance. Fig. 1 has been drawn for two machines having a considerable droop in their external characteristics and fig. 2 has been drawn for machines with only a small droop. The difference between the curves 1a and 1b is the same in both cases. A comparison of the two diagrams shows that the change produced in the machine currents is much larger for the machines with the flatter characteristics. On large machines where the external characteristics are very flat and the internal resistances very low, the small variations in voltage which are for ever occurring, can cause considerable fluctuations in the load of the individual machines, even when the total load is constant. This cannot be regarded as a satisfactory state of affairs because if the machines are operating at full load and transfer of load from one

machine to the other occurs, the second machine will be overloaded. To get satisfactory parallel operation it is essential that the voltage of the generators should fall continuously as the load increases. Experience indicates that this condition will usually be fulfilled if the drop in voltage from no load to full load is about 10 per cent. This is therefore the minimum voltage drop which will give satisfactory parallel operation and if possible it should be increased to 15 per cent.

GRAPHICAL DISCUSSION OF COMPOUND DYNAMOS IN PARALLEL.

From what has been said about shunt wound dynamos in parallel it should be apparent that level compound wound dynamos will not run in parallel without special precautions, and conditions will be even worse if the machines are overcompounded. W.M. Mordey[2] first pointed out that compound wound generators can be made to run satisfactorily in parallel by connecting the series fields in parallel by an equalising connection as shown in fig. 3. The equaliser can only make the generators operate satisfactorily in parallel if certain conditions are fulfilled. To determine what these conditions are, a detailed analysis is necessary; this analysis must take into account the inherent characteristics of the machines and the effect of the equaliser on them.

Fig. 4 shows what happens when two nominally identical compound wound generators with an equalising connection are run in parallel. This diagram has been drawn for two machines each rated at 40 amperes and overcompounded so that the terminal volts vary from 220 volts at no load to 230 volts at full load. In the diagram two families of curves are plotted showing the relationship between the terminal volts and ampere turns excitation on the fields for various currents flowing in the armature and series winding. These curves are easily calculated and allow for the effects of armature reaction, volt drop and variations in speed with load. When running on no load with the shunt regulator set to give 220 volts the shunt resistance lines are OA_1 and OA_2. When the armature current is 20 amperes the corresponding series excitation is 360 ampere turns represented by OB_1 and OB_2 in the diagram, and the shunt resistance lines B_1C_1 and B_2C_2 start from B_1 and B_2 and are parallel to OA_1 and OA_2. Where the lines B_1C_1 and B_2C_2 cut the 20 ampere curves gives the generator terminal volts with 20 amperes flowing in the armature. Repeating this construction for armature currents of 10, 30, 40, 50 and 60 amperes gives the complete compounding curves of the generators when operating separately. When the two machines are operating in parallel with a total armature current of 40 amperes, each machine will normally be carrying 20 amperes in its armature and series winding. The volt drops in the two series windings will be equal and there will be no tendency for any current to flow in the equalising connection from one series winding to the other, and the terminal voltages of the two machines will be equal at 230 volts. The fact that there is no current flowing in the equaliser in these circumstances does not mean that the equaliser is unnecessary. Suppose that a disturbance lasts long enough for the machines to reach a new steady operating condition such that the armature current of machine 1 is 10 amperes and of machine 2 30 amperes, the volt drops in the series windings will no longer be equal and a current will flow through the equaliser from the series field of the heavily loaded machine (No 2) to the series field of the lightly loaded machine (No. 1). The actual distribution of the currents between the two series windings depends only on the resistance of the series fields and equalising connection and is independent of the machine characteristics. If the resistance of the equaliser is equal to the

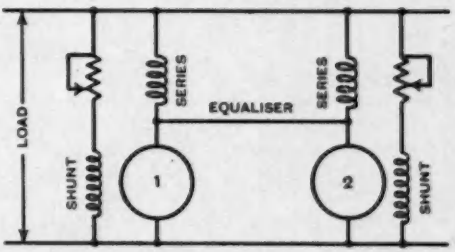

Fig. 3.—Essential connections for parallel operation of compound wound generators.

resistance of the series fields then the currents in the series fields can be calculated from equation (26) given later and will be found to be 16·7 amperes in the field of machine 1 and 23·3 amperes in the field of machine 2, the corresponding armature currents still being 10 and 30 amperes respectively.

This current distribution cannot continue after the passing of the disturbance which produced it, because as soon as the disturbance passes the armature currents are restored to equality by extra e.m.f.'s which are induced

in the armature; that is, the unequal load distribution is a purely transient condition which cannot continue after the passing of the disturbance which caused it. To show that this is so, suppose that after the passing of the disturbance these conditions still hold, then the series ampere turns of machines 1 and 2 are 300 and 420 ampere turns respectively and are represented by OD_1 and OD_2 in fig. 4. It should be noted that the total series excitation D_1D_2 after the disturbance, is the same as the original series excitation B_1B_2. The shunt resistance lines must now start from D_1 and D_2, and have been drawn in dotted, and cut the 10 ampere and 30 ampere curves of machines 1 and 2 at 237 volts and 223 volts respectively, so that there would be a difference of 14 volts between the terminals of the two generators, neglecting the difference in the voltage drops in the two series windings. This voltage difference must immediately cause a current to flow from the armature of machine 1 to the armature of machine 2 through the equaliser. The rate of growth of this current is such that this 14 volts is just balanced by the sum of all the e.m.f.'s of self induction appearing in the armatures and series windings of the two machines. There will be very little, if any, difference between the e.m.f.'s induced in the two machines and they can be taken as equal, the e.m.f. of self induction in each machine is therefore 7 volts. The corresponding terminal volts of machine 1 will be 237−7 or 230 and the terminal volts of machine 2 will be 223+7 or 230 and the terminal volts of the two machines are thus restored to equality at practically the same value as before. The armature terminal volts will not be equal, but will differ by an amount equal to the voltage drop in the equaliser.

The current flowing from machine 1 to machine 2 flows through the equaliser in opposition to the current already flowing in it due to the difference of voltage drop in the series coils, and the current flowing in the equaliser will therefore be reduced and may even be temporarily reversed. The flow of current from machine 1 to machine 2 also results in an increase of load on machine 1 and a decrease of load on machine 2. The current in the series winding of machine 1 will also increase, though not so much nor so rapidly as the armature current; similarly the current in the series winding of machine 2 will decrease. This process must continue until the currents in the armatures and series windings of the two machines are equal and steady and the current in the equaliser is zero. There will be no tendency for machine 1 to take more than its proper share of the load,

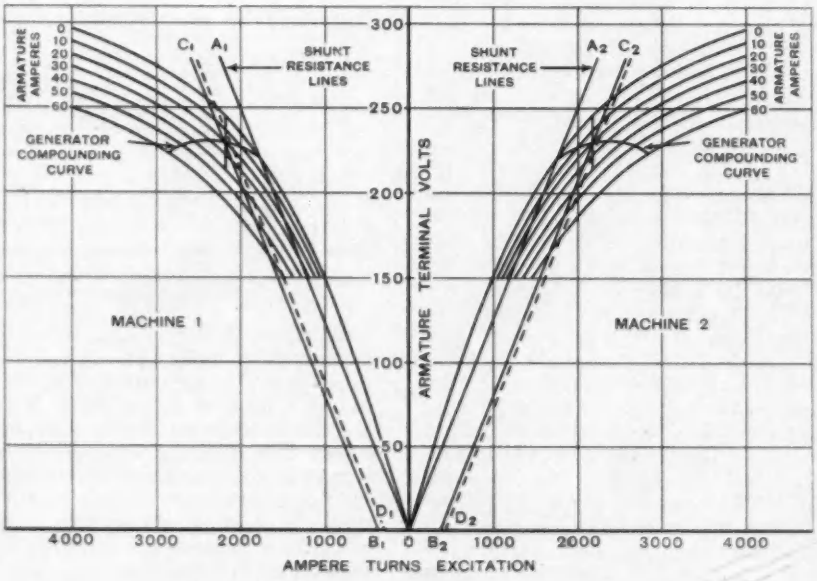

Fig. 4.—Parallel operation of compound wound generators

for if it did so the necessary e.m.f.'s for transferring the excess back to machine 2 would appear immediately. The worst that would happen is an oscillation of load from one machine to the other. In the absence of any disturbing forces this oscillation will be rapidly damped out and the machines will settle down with equal and steady loads. The time taken will depend on the resistance and inductance of the various circuits in the machines but will always be short. The exact nature of the initial disturbance which resulted in the unequal loading of the two armatures has not been

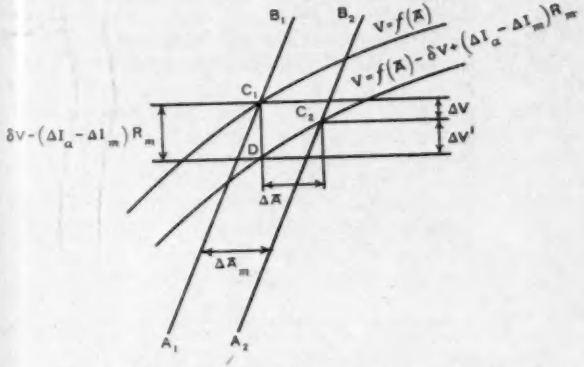

Fig. 5.—Enlargement of part of fig. 4 used in the development of equation (8).

specified, and it is not necessary to know it, as the discussion is limited to a consideration of the manner in which the armature currents are restored to equality after the disturbance has passed.

This discussion shows that an equaliser is effective because it ensures that when load is transferred from one machine to the other the generated voltage of the heavily loaded machine falls, while the generated voltage of the lightly loaded machine rises. This is exactly what happens when two shunt dynamos are run in parallel so that the conditions for the satisfactory parallel operation of either type of machine must be the same. It has already been pointed out that a voltage drop from no load to full load of 10 per cent to 15 per cent of the normal machine voltage will ensure satisfactory parallel running of shunt machines, hence if a correcting e.m.f. of 10 per cent to 15 per cent of the machine volts appears in the armature of each machine when full load is transferred from one compound wound machine to the other, then satisfactory parallel running should be obtained. When deciding on the correcting voltage required it should be remembered that 10 per cent correcting e.m.f. is the minimum permissible for shunt machines. In compound wound machines it is probably advisable to make the minimum a little higher than this, say 12½ per cent, because of possible inequalities in the series windings.

MATHEMATICAL DISCUSSION OF COMPOUND DYNAMOS IN PARALLEL.

The graphical procedure gives a good idea of what is happening in any particular case, but it is not easy to arrive at general conclusions from it. To do this, the procedure must be expressed mathematically. Let the equation

$$V = f(\bar{A}) \quad . \quad . \quad . \quad . \quad (1)$$

represent the relation between the terminal volts V of the generator and the ampere turns $\bar{A}$ on the field system with a specified current I_a flowing in the armature and series winding. Now if the armature and series currents are increased by a small amount $\triangle I_a$ then the terminal voltage for a given exciting ampere turns is reduced by a small amount δV. Fig. 4 shows that this decrease in voltage is practically constant over a large part of the mag-curve, and no appreciable error will be introduced by assuming that it is constant over the part of the curve under investigation. The equation of the mag-curve after the increase in load can therefore be written as :

$$V = f(\bar{A}) - \delta V \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Now when an equalising connection is fitted, the increase in the series current is not necessarily equal to the increase in the armature current. To distinguish between the two, denote the increase in series current by $\triangle I_m$. The increased voltage drop in the series winding will be $\triangle I_m R_m$ instead of $\triangle I_a R_m$ where R_m is the resistance of the series winding. Under these conditions equation (2) will become

$$V = f(\bar{A}) - \delta V + (\triangle I_a - \triangle I_m) R_m \quad . \quad (3)$$

In fig. 5 which is merely a small part of fig. 4 re-drawn to a much larger scale, let the curve $V = f(\bar{A})$ represent the initial mag-curve and the curve $V = f(\bar{A}) - \delta V + (\triangle I_a - \triangle I_m) R_m$ represent the mag-curve with the increased armature and series currents. The shunt resistance line is initially A_1B_1 cutting the curve $V = f(\bar{A})$ at C_1. The effect of the increase $\triangle I_m$ in the series current is to increase the series excitation $\bar{A}_m$ by $\triangle \bar{A}_m$ so

that the shunt resistance line moves a distance $\triangle \bar{A}_m$ parallel to itself to the position A_2B_2 and cuts the second curve at the point C_2. The terminal voltage is altered by the amount $\triangle V$ which for the conditions shown in the diagram is a reduction in voltage. The diagram is plotted as volts against ampere turns so that the slope of the shunt resistance lines in the diagram is

$$\frac{V}{\bar{A}_s} = \frac{V}{I_s T_s} = \frac{R_s}{T_s} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $\bar{A}_s$ is ampere turns excitation due to shunt winding, I_s is the current flowing in the shunt winding, T_s is the number of turns in the shunt winding, and R_s is the resistance of the shunt circuit including any external regulating resistance in series with the shunt coils. If the terminal volts of the machine alter by $\triangle V$ then the shunt excitation alters by $\triangle \bar{A}_s$ given by

$$\triangle \bar{A}_s = \frac{T_s}{R_s} \triangle V \quad . \quad . \quad . \quad . \quad . \quad (5)$$

If $\bar{A}$ denotes the total excitation on the fields then $\bar{A}$ is merely the sum of the shunt and series excitations and the change $\triangle \bar{A}$ in the total excitation is the sum of the changes in the shunt and series excitations so that

$$\triangle \bar{A} = \triangle \bar{A}_m + \frac{T_s}{R_s} \triangle V \quad . \quad . \quad . \quad (6)$$

From fig. 5 it is obvious that

$$\delta V - (\triangle I_a - \triangle I_m) R_m = \triangle V + \triangle V'$$

Therefore

$$\triangle V = \delta V - (\triangle I_a - \triangle I_m) R_m - \triangle V'$$

Now the two curves $V = f(\bar{A})$ and $V = f(\bar{A}) - \delta V + (\triangle I_a - \triangle I_m) R_m$ are separated by the constant distance $\delta V - (\triangle I_a - \triangle I_m) R_m$ so that the gradients of the two curves must be equal at any two points such as C_1 and D which require the same total excitation. At the point C_2 where the total excitation has increased by the small amount $\triangle \bar{A}$, the slope will have decreased slightly, but as $\triangle \bar{A}$ is small the change in slope will be of the second order of small quantities and can be neglected. In the region $C_1 D C_2$ the slope of the curves is constant and can be denoted by the usual symbol $\frac{\triangle f(\bar{A})}{\triangle \bar{A}}$

Hence referring to fig. 5 it is clear that

$$\frac{\triangle V'}{\triangle \bar{A}} = - \frac{\triangle f(\bar{A})}{\triangle \bar{A}}$$

Therefore

$$\triangle V = \delta V - (\triangle I_a - \triangle I_m) R_m + \frac{\triangle f(\bar{A})}{\triangle \bar{A}} \triangle \bar{A} \quad (7)$$

Substituting the value of $\triangle \bar{A}$ given by equation (6) in equation (7) and rearranging gives

$$\triangle V = \frac{\delta V - (\triangle I_a - \triangle I_m) R_m + \frac{\triangle f(\bar{A})}{\triangle \bar{A}} \triangle \bar{A}_m}{I - \frac{T_s}{R_s} \frac{\triangle f(\bar{A})}{\triangle \bar{A}}} \quad (8)$$

Equation (8) has many applications in the theory of direct current generators and can be used in conjunction with Kirchhoff's Laws to determine the permissible resistance of the equalising connection for satisfactory parallel running. For convenience fig. 3 has been redrawn as fig. 6, the shunt circuits are omitted and the currents and resistances of the various circuits indicated for two identical machines. Suppose the machines are properly adjusted to carry equal armature currents with equal generated e.m.f.'s. After the passing of some disturbance, such as a change in speed of one machine, the armature currents are no longer equal. The armature current of machine 2 is increased by $\triangle I_a$ and the armature current of machine 1 is decreased by the same amount. The series currents and voltage drops will also be unequal; the series currents of

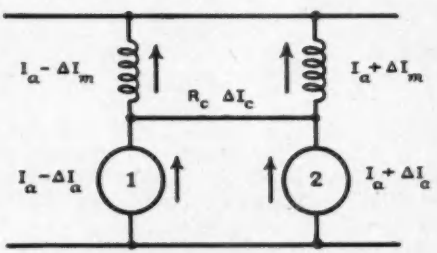

Fig. 6.—Simplified diagram of connections for the parallel running of compound wound generators.

machines 2 and 1 will have increased and decreased by $\triangle I_m$ respectively, and a current $\triangle I_c$ must be flowing in the equaliser. The current flowing in the equaliser is the difference between the armature and series currents and is given by

$$\triangle I_c = \triangle I_a - \triangle I_m \quad . \quad . \quad . \quad . \quad (9)$$

The graphical discussion has shown that if the equaliser is going to be effective then this re-distribution of the armature and series currents must immediately result in e.m.f.'s being generated in the armature. These e.m.f.'s must be in opposition to the current $\triangle I_a$ which will then immediately start to decrease. Inductive e.m.f.'s will appear in various parts of the circuit opposing this decrease but not preventing it. As the

machines are supposed to be close together the resistance of the busbars will be negligible compared with the other resistances in the circuit. Hence applying Kirchhoff's second law to the loop circuit consisting of the two series windings and equalising connection gives :—

$$R_m(I_a + \triangle I_m) - R_m(I_a - \triangle I_m) - R_c \triangle I_c + (E'_{m2} - E'_{m1}) = 0$$

where E'_{m2} and E'_{m1} are the inductive e.m.f.'s appearing in the series coils while the current is changing. This reduces to

$$2\triangle I_m R_m - \triangle I_c R_c + (E'_{m2} - E'_{m1}) = 0$$

The two series currents must be altering at the same rate except that the one is increasing and the other decreasing and the inductances of the two field systems are equal

Therefore $E'_{m1} = -E'_{m2}$

Therefore

$$2\triangle I_m R_m - \triangle I_c R_c + 2E'_{m2} = 0 \quad (10)$$

Now substitute the value of $\triangle I_m$ given by equation (9) in equation (10) and re-arrange thus :

$$\triangle I_c = \frac{2\triangle I_a R_m + 2E'_{m2}}{2R_m + R_c} \quad . \quad . \quad . \quad (11)$$

Before the disturbance the internal e.m.f.'s and terminal voltages of both machines are related by the expression

$$E = V + I_a R_a + I_a R_m \quad . \quad . \quad . \quad (12)$$

After the passing of the initial disturbance leaving the unequal current distribution the equations of the two machines become

$$E + \triangle E_2 = V + \triangle V_2 + (I_a + \triangle I_a) R_a + (I_a + \triangle I_m) R_m \quad . \quad (13)$$

$$E + \triangle E_1 = V + \triangle V_1 + (I_a - \triangle I_a) R_a + (I_a - \triangle I_m) R_m \quad . \quad (14)$$

Subtracting equation (12) from equations (13) and (14) gives

$$\triangle E_2 = \triangle V_2 + \triangle I_a R_a + \triangle I_m R_m \quad . \quad (15)$$

$$\triangle E_1 = \triangle V_1 - \triangle I_a R_a - \triangle I_m R_m \quad . \quad (16)$$

As both machines were operating initially at the same points on their mag-curves and the increase in current in one machine is equal to the decrease in current of the other it follows immediately from equation (8) that

$$\triangle V_1 = -\triangle V_2 \quad . \quad . \quad . \quad . \quad . \quad (17)$$

and hence from equations (15) and (16) that

$$\triangle E_1 = -\triangle E_2 \quad . \quad . \quad . \quad . \quad . \quad (18)$$

so that equation (15) reduces to equation (16). Now applying Kirchhoff's second law to the loop circuit consisting of the two armatures and the equalising connection, this gives :

$$(E + \triangle E_2) - (E + \triangle E_1) = (I_a + \triangle I_a) R_a + \triangle I_c R_c - (I_a - \triangle I_a) R_a + (E'_{a2} - E'_{a1})$$

Where E'_{a2} and E'_{a1} are the inductive e.m.f.'s appearing in the armature circuit. As with the inductive e.m.f.'s appearing in the series winding

$$E'_{a2} = -E'_{a1}$$

Therefore

$$2\triangle E_2 = 2\triangle I_a R_a + \triangle I_c R_c + 2E'_{a2} \quad (19)$$

Now substitute the value of $\triangle E_2$ given by equation (15) in equation (19) then

$$2\triangle V_2 = \triangle I_c R_c - 2\triangle I_m R_m + 2E'_{a2} \quad . \quad (20)$$

From equation (9) this becomes

$$2\triangle V_2 = \triangle I_c(R_c + 2R_m) - 2\triangle I_a R_m + 2E'_{a2} \quad (21)$$

Equality of load can only be restored by current flowing through the equaliser from machine 1 to machine 2 and equation (21) shows that this current will only flow if the correcting voltage $2\triangle V_2$ is greater than $\triangle I_c(R_c + 2R_m) - 2\triangle I_a R_m$ and so is able to reduce the currents $\triangle I_a$ and $\triangle I_c$ to zero in spite of the inductive e.m.f.'s $2E'_{a2}$ which appear in the circuit. The maximum permissible resistance of the equaliser R_{cL} is given by

$$2\triangle V_2 = \triangle I_c(R_{cL} + 2R_m) - 2\triangle I_a R_m \quad . \quad (22)$$

because when this condition is fulfilled the currents $\triangle I_a$ and $\triangle I_c$ will remain constant without any tendency to increase or decrease, and no inductive voltages will appear in the circuit so that E'_{m2} and E'_{a2} will each be equal to zero, and equations (10) and (20) will become

$$2\triangle I_m R_m - \triangle I_c R_{cL} = 0 \quad . \quad . \quad . \quad (23)$$

$$2\triangle V_2 = \triangle I_c R_{cL} - 2\triangle I_m R_m \quad . \quad . \quad (24)$$

Equations (23) and (24) can be simultaneously satisfied only if

$$\triangle V_2 = 0$$

This result might on first thoughts be considered to be self evident, but is not really so because $\triangle V_2$ is the change which must be produced in the steady state terminal voltage of the machines by the change $\triangle I_a$ and $\triangle I_m$ in the currents. When the change in the terminal voltage is zero the change in the armature e.m.f.'s is not zero and can, if desired, be determined from equation (15). When the equaliser has its critical resistance R_{cL} equation (8) becomes

$$\delta V - (\triangle I_a - \triangle I_m) R_m + \frac{\triangle f(\bar{A})}{\triangle \bar{A}} \triangle \bar{A}_m = 0 \quad (25)$$

At the same time equation (11) becomes

$$\triangle I_c = \frac{2\triangle I_a R_m}{2R_m + R_{cL}} \quad . \quad . \quad . \quad . \quad (26)$$

Also $\triangle \bar{A}_m = \triangle I_m T_m = (\triangle I_a - \triangle I_c) T_m$

Therefore

$$\triangle \bar{A}_m = \triangle I_a T_m \left(1 - \frac{2R_m}{2R_m + R_{cL}}\right) \quad (27)$$

Substituting these values in equation (25) and re-arranging gives eventually

$$R_{cL} = \frac{-2R_m \dfrac{\delta V}{\triangle I_c} + 2R_m^2}{\dfrac{\delta V}{\triangle I_a} + T_m \dfrac{\triangle f(\bar{A})}{\triangle \bar{A}}} \quad . \quad . \quad . \quad (28)$$

From equation (28) the critical resistance of the equaliser can be determined when a family of mag-curves such as is shown in fig. 4 is available, as both $\dfrac{\triangle f(\bar{A})}{\triangle \bar{A}}$ and $\dfrac{\delta V}{\triangle I_a}$ can be read from the diagram.

From equations (10) and (20) it follows immediately that

$$\triangle V_2 = E'_{a2} + E'_{m2} \quad . \quad . \quad . \quad . \quad (29)$$

so that the change in voltage due to the changes $\triangle I_a$ and $\triangle I_m$ in the current, calculated from equation (8), is entirely absorbed in overcoming the inductive e.m.f.'s appearing in the circuit, and the larger $\triangle V_2$ is for a given change, the more rapidly and surely will the disturbance be corrected.

To obtain satisfactory parallel running of two nominally identical machines which are actually subject to all the minor differences which can occur in practice, it is necessary to make sure that the equaliser has a very definite correcting action.

As pointed out in the graphical analysis, satisfactory parallel running of compound wound generators will be obtained if a correcting e.m.f. of 10 per cent to 15 per cent of the machine volts appears in the armature of each machine when full load is transferred from one machine to the other. As the armatures of compound wound generators are connected in parallel by the equalising connection and one of the busbars, in exactly the same way as the armatures of two shunt machines are connected in parallel by the busbars, the logical procedure is to base the calculation of the equaliser resistance on the armature terminal volts V_a rather than on the machine terminal volts V. This distinction was not made in the graphical analysis because it would complicate the diagrams. If $\triangle V_a$ denotes the desired correcting voltage expressed as a fraction of the armature terminal volts when full load is transferred from one machine to the other, then in practice it will suffice to assume that $\triangle V_a$ is $0{\cdot}1V_a$ or $0{\cdot}15V_a$ when full load is transferred from one machine to the other, so that

$$\frac{\triangle V_a}{\triangle I_a} = \frac{0{\cdot}1V_a}{I_a} \text{ or } \frac{0{\cdot}15V_a}{I_a}$$

This procedure is equivalent to neglecting the curvature of the generator load curve and automatically gives compound wound machines a slightly higher correcting voltage than shunt machines having a drop in voltage of 10 per cent or 15 per cent. This margin should compensate for any ill-effects due to differences in the resistances of the series windings. As this method of determining the resistance of the equaliser is based essentially on giving the generators the necessary steady state characteristics, no transient e.m.f.'s will appear in the equations.

Equation (15) can be written as

$$\triangle V_a = \triangle V + \triangle I_m R_m$$

Therefore $$\frac{\triangle V_a}{\triangle I_a} = \frac{\triangle V}{\triangle I_a} + \frac{\triangle I_m}{\triangle I_a} R_m \quad . \quad . \quad . \quad . \quad (30)$$

The value of $\triangle V$ is given by equation (8), the relationship between the current changes by equation (9), the current flowing in the equaliser by equation (26) and the change in series excitation by equation (27). From these it follows that equation (30) becomes

$$\frac{\triangle V_a}{\triangle I_a} = \frac{\triangle I_m}{\triangle I_a} R_m + \frac{\dfrac{\delta V}{\triangle I_a} - \left(1 - \dfrac{\triangle I_m}{\triangle I_a}\right) R_m + \dfrac{\triangle f(\bar{A})}{\triangle \bar{A}} T_m \dfrac{R_c}{2R_m + R_c}}{1 - \dfrac{T_s}{R_s} \dfrac{\triangle f(\bar{A})}{\triangle \bar{A}}}$$

After some reduction this gives

$$\frac{2R_m}{R_c} = \frac{T_m \dfrac{\triangle f(\bar{A})}{\triangle \bar{A}} + 2R_m}{\dfrac{\triangle V_a}{\triangle I_a}\left(1 - \dfrac{T_s}{R_s} \dfrac{\triangle f(\bar{A})}{\triangle \bar{A}}\right) - \dfrac{\delta V}{\triangle I_a} + R_m} - 1 \quad (31)$$

From equation (31) the resistance of the equaliser can be calculated quite easily and accurately provided that a family of mag-curves such as those shown in fig. 4 is available. Unfortunately, the preliminary work involved in calculating the curves of fig. 4 is considerable, and they are not often required in normal design procedure. To give some indication of the permissible value of the equaliser

resistance the curves shown in fig. 7 have been calculated for a range of level compound wound generators of normal design, and show the value of R_c/R_m plotted against armature D^2L when D and L are in cms.

This curve must not be regarded as more than a rough guide, as the points through which the three lines are drawn are somewhat scattered. The top curve shows the value of the ratio R_{cL}/R_m. The second curve shows the value of the ratio R_c/R_m calculated for a value of $\frac{\triangle V_a}{\triangle I_a}$ corresponding to an initial slope of 10 per cent and the third shows the value of $\frac{R_c}{R_m}$ corresponding to an initial slope of 15 per cent. The amount of scatter in the points is a maximum in the curve of R_{cL}/R_m and a minimum in the curve of R_c/R_m corresponding to a correcting voltage of 15 per cent. When calculating the points for these curves it was noted that if the flux in the machine was low then the ratio of R_c/R_m was low. The effect is greater the higher the resistance of the equaliser and probably accounts for the variation in the amount of scatter in the results. From fig. 7 it is obvious that if the equaliser is going to be really effective its resistance must be much less than the critical resistance. In very large compensated machines it may not be possible to get a 10 per cent correcting voltage even with an equaliser of zero resistance. The maximum obtainable value of $\frac{\triangle V_a}{\triangle I_a}$ corresponds to R_c equal to zero, and from equation (31) it is obvious that this corresponds to

$$\left(\frac{\triangle V_a}{\triangle I_a}\right)_{max}\left(1-\frac{T_s}{R_s}\frac{\triangle f(\bar{A})}{\triangle \bar{A}}\right)-\frac{\delta V}{\triangle I_a}+R_m=0$$

$$\text{Therefore}\left(\frac{\triangle V_a}{\triangle I_a}\right)_{max}=\frac{\frac{\delta V}{\triangle I_a}-R_m}{1-\frac{T_s}{R_s}\frac{\triangle f(\bar{A})}{\triangle \bar{A}}} \quad . \quad (32)$$

In large machines, where there may be reason to expect difficulty in parallel running, it is advisable to determine this value at the earliest possible stage in the design. The difficulty can be got over by the well known artifice of putting in a little counter series excitation between the armature and the equaliser connection and increasing the main series excitation by a corresponding amount.

Equation (31) can be used to investigate the effect of long leads from the machine to the switchboard; the general effect is that as R_m is increased the ratio of R_c/R_m increases slightly. Hence the safe procedure is to specify the ratio neglecting the effects of long leads.

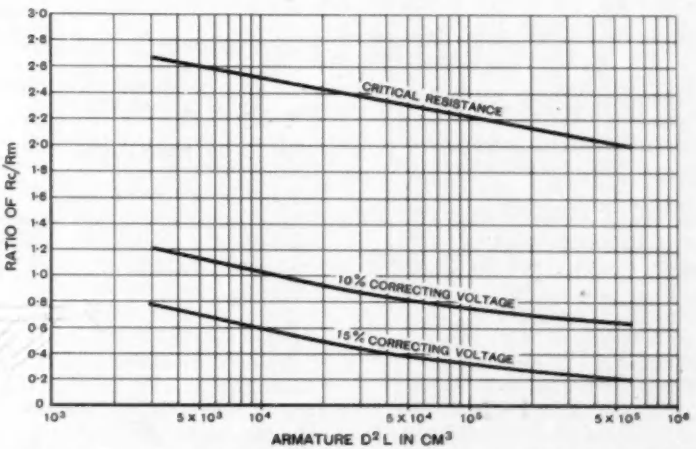

Fig. 7.—Curves for determining permissible resistance of equalising connection between two level compounded generators operating in parallel.

When using fig. 7 to determine the permissible resistance of the equalising connection between two machines of the same output, the procedure is as follows :

With the equalising switch open, determine the resistance R_m between the equalising terminal of the generator which is connected to one end of the series winding and the busbar which is connected to the other end of the series winding. This will include the resistance of the series coils, the cable to the switchboard, joints and circuit breakers. Measure the diameter D and the length L of the armature in centimetres, and evaluate D^2L. This should be done for both machines. If the resistance and the D^2L are the same for both machines, or do not differ by more than a few per cent, then read off the value R_c/R_m from fig. 7, using the curve marked "10 per cent correcting voltage," and evaluate R_c. If there is a big difference in the value of the D^2L for the two machines, but the resistances R_m are approximately equal, then the safe procedure is to read off the value of the R_c/R_m from the curve marked "10 per cent correcting voltage" corresponding to the D^2L of the bigger machine. If there is a big difference in the resistances R_m all possible steps should be taken to make them equal,[3] but if when this has been done there is still a big difference in the resistance, say about 10 per cent, then the maximum possible correcting voltage is required and the value of R_c/R_m should be read from the curve marked "15 per cent correcting voltage."

It should be particularly noted that fig. 7 is drawn for machines of normal design and construction, in a state of normal adjustment, and should not be applied to machines with compoles abnormally weak or strong, or to machines running with the brushes a long way out of neutral, or with specially graded airgaps to reduce armature reaction. In all doubtful cases it is advisable to consult the manufacturers of the machine.

This paper has been limited to a discussion of the parallel running of two nominally identical machines, but it is possible to extend the analysis to the parallel operation of unequal generators which will be dealt with in a later article.

REFERENCES.

1. The Diagnosing of Troubles in Electrical Machines. MILES WALKER. pp. 274—277.
2. Dynamo Electric Machinery. S. P. THOMPSON. *Edition* 1904. p. 928.
3. Parallel Operation of Direct Current Generators. M. S. HANCOCK. *Electric Journal*, November 1933.

Technical Literature.

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES.

THE TRANSMISSION CHARACTERISTICS OF ASYMMETRIC-SIDEBAND COMMUNICATION NETWORKS, PART II.*

By E. C. CHERRY (Research Laboratories).

J. I. E. E., Vol. 90, Part III, *p. 75, June, 1943.*

This paper, in continuation of Part 1, an abstract of which was given in the G.E.C. Journal, Vol. XII, No. 2, August, 1942, deals with the transmission of an amplitude-modulated wave through a bandpass channel, the transfer characteristics of which are not symmetrical, either in modulus or phase, or both, about the carrier frequency. This paper is not concerned, here, with any specific application of such asymmetric sideband working, perfectly general forms of modulating wave and channel characteristics have been assumed. The theorem, given in Part I, expressing the "equivalent modulation frequency characteristics" of such a channel in terms of the bandpass characteristics, is here considered in greater detail.

The idealised transfer characteristics chosen by various authors for analysis of asymmetric-sideband channel distortion are examined in the light of this theorem, as are also the characteristics of a generalised tuned circuit amplifier stage (or series of stages), taken as a practical example.

The theorem is again extended to include

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the case of a carrier wave modulated by an envelope wave which rises or decays at a rate greater than that of the carrier itself; (that is, a wave spectrum containing "negative" sidebands).

An appendix is included, giving some notes on the wave form of such a modulated wave.

THE SEPARATION OF METALS BY MEANS OF THE MERCURY CATHODE : CHROMIUM*

By R. C. CHIRNSIDE, L. A. DAUNCEY and P. M. C. PROFFITT (Research Laboratories).

Analyst, Vol. 68, p. 175, June, 1943.

An investigation has been made into the conditions necessary for the separation of chromium over a mercury cathode. In particular, the factors affecting the rate of deposition of chromium in the presence of ammonium sulphate have been studied. High current density, elevated temperatures, concentrated solutions, minimum acidity, have all been found to increase the rate. Rotation of the anode or addition of reducing agents, appears to prevent the deposition. Alkali metals are without effect.

When ammonium sulphate is present in amount such as to inhibit, partially or completely, the deposition of chromium, the difficulty may be overcome by the addition of small quantities of nickel or very small, but critical, amounts of silver to the electrolyte.

It has been found also that the deposition of chromium takes place readily in presence of copper or iron, such as might be encountered in copper-chrome or ferro-chrome.

DIODE FREQUENCY CHANGERS.*

By E. G. JAMES and J. E. HOULDIN (Research Laboratories of The G.E.C. and M.O. Valve Co.).

Wireless Engineer, Vol. 20, p. 15, January, 1943.

A general analysis of a two-element frequency changer is given, and the results are applied to diodes having (*a*) a three-halves power characteristic and (*b*) an exponential characteristic. It is shown that: (1) when circuit losses are negligible, if the ratio of the output power to the input power is adjusted to be optimum, the generator resistance, the input and output resistance of the diode and the I.F. load resistance are equal, and the optimum power ratio is given by

$$M = \frac{g_c^2}{[g_0 + \sqrt{(g_0^2 - g_c^2)}]^2}$$

where g_0 is the mean conductance of the diode and g_c is the conversion conductance.

(2) when the input circuit loss is not negligible, the optimum effective power ratio is

$$M_e = \frac{g_c^2}{[\sqrt{g_0(g_0+G_1)} + \sqrt{g_0(g_0+G_1) - g_c^2}]^2}$$

where G_1 is the conductance of the input circuit. In this case, the diode ouput resistance is equal to the I.F. load resistance and the generator resistance is equal to the effective input resistance of the diode but the equality between input and output resistance does not hold.

When circuit losses are present, the power ratio calculated when the I.F. frequency is equal to the difference between the signal and oscillator frequencies is always greater than that obtained when the I.F. frequency is equal to the difference between the signal frequency and a multiple of the oscillator frequency; the difference increases as G_1 increases. When operating on a multiple of the oscillator frequency, it is possible that the power ratio may be greater than that calculated if harmonics are present in the oscillator.

Although the diode, when used as a frequency changer, is essentially a non-linear device, an equivalent circuit, consisting of a π–network of linear resistances, can be drawn, from which its performance can be deduced. Each leg of the π–network is equal to $g_0 - g_c$ and the bar is equal to g_c, g_0 and g_c being defined as above.

HIGH-FREQUENCY RESISTANCE OF PLATED CONDUCTORS.*

By R. FARADAY PROCTOR (Research Laboratories).

Wireless Engineer, Vol. 20, p. 56, February, 1943.

Schelkunoff has derived an expression for the H.F. impedance of a laminated, or plated conductor, in terms of the surface and transfer impedances of its constituent layers. His expression lends itself to numerical calculations as the various impedances can be readily evaluated with the aid of tables. It also has the advantage of being easily applied to conductors having any number of layers of plating.

It is shown how Schelkunoff's expression may be derived, in the case of plane conductors, from the normal uniform line equations, by a simple extension of the method proposed by Howe for calculating the skin resistance of plain conductors. The results are extended to cover conductors of any arbitrary cross-section.

Expressions are derived for the surface and

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transfer impedances of hollow cylinders and the surface impedance of solid cylinders or rods. Tables have been prepared enabling the surface impedance of a cylindrical, or plane, plated conductor to be readily calculated. Curves are given of the surface impedance of plane plated conductors composed of tinned copper, copper-plated iron, and nickel-plated copper. The results which may be expected from the use of copper-plated iron conductors as a means of equalising the attenuation of a co-axial cable over a wide band of frequencies are indicated.

TRAVELLING WAVES IN HIGH VOLTAGE ALTERNATOR WINDINGS.*

By E. FRIEDLÄNDER (Research Laboratories).

J.I.E.E., Vol. 89, Part II, p. 492, 1942.

The security of the windings of an alternator generating at 22 kV or above and connected directly to a network depends mainly on the ability of the insulation to withstand surge voltages.

The distribution of surge voltages in the various types of stator winding hitherto adopted in commercial practice is examined together with the relation of this distribution to that of the effective insulation available.

As alternators nearly always operate with the neutral point unearthed, the voltage stresses on the insulation near the neutral in these circumstances are determined and the danger of the use of graded insulation is discussed.

In no case does there appear to be an inherent tendency for all transient voltages to be distributed over the length of the stator winding in the same proportion as the generated voltage of the machine.

VOLTAGE FLUCTUATIONS IN RESISTORS (JOHNSON EFFECT).*

By N. R. CAMPBELL and V. J. FRANCIS (Research Laboratories).

Phil. Mag., Vol. 34, p. 259, April, 1943.

Gives a proof of Johnson's formula for thermal fluctuations based on the principles of Brownian motion and exhibiting the relation between the Johnson effect in resistors and the shot effect in a saturated electronic current.

CLASS C TELEGRAPHY. THE GRAPHICAL DETERMINATION OF OPTIMUM OPERATING CONDITIONS FOR TRANSMITTING VALVES.*

By D. G. PRINZ and R. G. MITCHELL (Research Laboratories of The G.E.C. and M.O. Valve Co.).

Wireless Engineer, Vol. 19, p. 401, September, 1942.

The derivation is given of sets of curves, which enable optimum operating conditions for transmitting valves to be determined for Class C telegraphy operation and the use of these curves explained.

THE BEHAVIOUR OF TUCK STONES IN A GLASS TANK FURNACE.*

By J. H. PARTRIDGE (Research Laboratories).

J.Soc. Glass Tech., Vol. 26, p. 172 (T), August, 1942.

The peritectic reaction mullite $\longrightarrow$ corundum + siliceous liquid occurred in a 40 per cent aluminous material used for tuck stones in a glass tank furnace, and the liquid matrix flowed down the faces of the tank blocks. The fluidity of the glassy matrix of a number of refractory specimens submitted for use as tuck stones was examined by observing the creep under low tensile stress at 1350 and 1400 degs.C. The resistance to corrosion by soda-lime-silica glass was also tested and as a result the aluminous material was replaced by silica with beneficial results which are described.

X-RAYS IN THE INDUSTRIAL LABORATORY.*

By H. P. ROOKSBY (Research Laboratories).

J. Roy Soc. Arts, Vol. 90, p. 673, 1942.

The three Cantor Lectures deal with various aspects of the application of X-rays in industrial development and research work. In the first lecture the principles and technique of radiography are discussed and the radiographic examination of castings and valve assemblies described. The second and third lectures deal with the technique of the X-ray analysis of crystals. It is shown how the analytical results of the chemist and metallurgist are amplified and elaborated by the use of X-ray methods, with information unobtainable by other means. In particular the use of X-ray analysis for identification, the study of polymorphic forms, the examination of solid solution effect, crystal size measurements and the detection of lattice strain is described.

NOTES ON TRACKING CIRCUITS.*

By A. BLOCH (Research Laboratories).

Wireless Engineer, Vol. 19, p. 508, November, 1942.

The paper consists of three parts. The principle of duality is applied to derive design formulae for inductance tuned circuits from those for capacity tuned circuits. A similar circuit transformation is used to derive circuits which track with constant difference of wavelength. Finally, a general formula for the "tracking error" is developed which expresses this error in

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terms of these frequencies (wavelengths) at which the tracking is correct.

ARC WELDING AND WAR PRODUCTION.*
By E. C. DAVIES (Engineering Works, Witton).
G.E.C. Journal, Vol. XII, No. 2, p. 63, August, 1942.
Reprinted in Production and Engineering Bulletin, p. 131, Dec., 1942.
Engineer, Vol. 174, No. 4524, Sept. 25th, and No. 4525, Oct. 2nd, 1942.

The article urges the examination of existing manufacturing methods with a view to substituting fabrication by welding for riveting, casting, forging, etc., as a means of accelerating production. It is also suggested that by modernising welding methods, work now done by this means could be improved and speeded up. The applications and advantages of high speed welding are discussed. Some notes on the selection of welding plant are included with a review of the relative merits of D.C. and A.C. welding.

THE ADVANTAGES OF HIGH AMPERAGE WELDING.
By E. C. DAVIES (Engineering Works, Witton).
An address delivered before the Institute of Welding (North Eastern Branch), April, 8th, 1943. Published in "Welding," July, 1943.

A plea for an appreciation of the advantages offered by high-speed and deep penetration welding methods, quoting typical examples of applications and characteristics of resultant welds.

MARINE APPLICATIONS OF ELECTRICITY—(1) INTRODUCTORY SURVEY.
By H. W. WILSON (Engineering Works, Witton).
Shipping World, Vol. 107, No. 2571, p. 241, September 23rd, 1942.

An introductory survey to a series of articles by various authors, since published, in which the developments and prospects of electricity in its many applications on board ship were discussed.

(iii). ELECTRIC PROPULSION.
By R. G. JAKEMAN (Engineering Works, Witton).
Shipping World, November 18th, 1942.

A comparative review of the practicable systems available for ship propulsion, including turbo-electric A.C., Diesel-electric A.C. or D.C., with some notes on the magnetic slip coupling.

RECORDING OF MECHANICAL PRESSURES WITH THE CATHODE RAY OSCILLOGRAPH.
By W. WILSON (Witton Development Laboratory).
B.E.A.M.A. Journal, September, 1942, p. 254.

The various types of pick-up for converting pressure to voltage are described, including the microphone and the piezo-electric resistance, inductance and capacitance types. Examples of their use are given, including sound analysis, indication of automobile and aero engines, recording of bomb pressures and pile driving impulses.

THE ELECTRON MICROSCOPE AND DIFFRACTION CAMERA.
By W. WILSON (Witton Development Laboratory).
B.E.A.M.A. Journal, October, November and December, 1942, pp. 300, 325 and 381.

The very extensive increase in the field of microscopy due to the substitution of cathode rays for visible light is described. The limitations of the optical microscope are stated, and the means whereby an increased magnification of about 100 times has already been secured, is set forth. A description is also given of the electron diffraction camera, whereby the constitution of surface films of all kinds has been ascertained, examples of which are shown. Typical electron micrographs showing magnifications of up to 27 times the maximum power of the light microscope are given, including zinc oxide fumes (x 20,000), polymerised vinyl chloride (x 55,000), and the tobacco mosaic virus (x 55,000), the last named of which has already made history. Large views of the tuberculosis and typhoid microbes are also given.

FAULT PROTECTIVE GEAR.
By W. WILSON (Witton Development Laboratory).
The Electrical Engineer (Australia), March and April, 1942, pp. 272 and 5 respectively.

A general survey is given of the various systems of protection available for all types of electrical equipment, with the respective advantages of each. The importance of a biased characteristic is stressed, and definite schemes are advocated for the most common cases.

A SIMPLE EXPANDER.
By W. BACON (Radio Development Laboratory).
Electronics (U.S.A.), December, 1941, p. 50.

A method of volume expansion using only very simple components is described.

Negative feedback is applied to an amplifier through an unbalanced bridge. One arm of this bridge includes a non-linear element (*e.g.*, a small lamp). Increase of output voltage is thus caused to bring the bridge more nearly into balance and hence to decrease the negative feedback. Theoretical expressions are worked out for the expansion thus obtained, which is shown to follow the correct law.

The method is easily applied to an existing amplifier.

A SIMPLE R.C. OSCILLATOR.
By W. BACON (Radio Development Laboratory).
Electronic Engineering, April, 1942, p. 707.

A short summary is given of the principal types of oscillator having as their frequency determining element a resistance capacity

* A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, Birmingham, 6.

network instead of a tuned circuit. A less well known circuit employing one valve only is described in more detail.

R.F. POWER MEASUREMENT.
By W. BACON (Radio Development Laboratory).
Electronic Engineering, January, 1943, p. 344.

A bolometric method is described by means of which powers of the order of a few watts at frequencies around 100 megacycles can be measured. A special feature is the separation of R.F. from D.C. by means of a double bridge. Formulae are given by means of which the values of the bridge components may be calculated. The system is simple and has the advantage of giving a direct reading of power. Over a certain range the scale is linear.

CONTROLLED ATMOSPHERES FOR HEAT TREATMENT PROCESSES.*
By S. V. WILLIAMS (Research Laboratories).
Metal Treatment, Summer, 1943, page 111.

The development and utilization in Great Britain of controlled atmospheres for heat-treatment purposes is reviewed. Atmospheres derived from ammonia hydrocarbons and carbon are considered. Of these the first two have been developed to a high degree of perfection and the choice of one or the other is determined by economic, furnace and metallurgical considerations. Carbon derivatives are not as yet in such general use but it is anticipated that they will find increasing application in the heat treatment of ferrous materials. The author concludes with a brief account of the application of controlled atmospheres for the heat treatment of ferrous and non-ferrous metals and alloys.

INFRA-RED LAMP HEATING APPLIED TO PAINT DRYING AND OTHER INDUSTRIAL HEATING APPLICATIONS.
By F. E. ROWLAND (G.E.C. Industrial Heating Department).
A paper read before the Seventeenth Joint Annual Meeting of the Institution of Engineers in Charge, and the Association of Supervising Electrical Engineers, November 14th, 1942.
Electrician, p. 575, November 27th, 1942.
Electrical Times, p. 748, November 19th, 1942.
Electrical Review, p. 655, November 20th, 1942.
Engineer, p. 429, November 27th, 1942.

One of the principal applications of infra-red lamp heating is the rapid drying of paint on metal surfaces, drying times of several hours being reduced to a few minutes. Temperatures of 500° to 600° F. are obtainable; 20 gauge sheet steel can be raised to 500° F. in two or three minutes.

Other applications include softening of plastics, evaporation of moisture from various products, and the drying of veneers and printing inks.

Many other applications are foreseen.

MODERN SYNTHETIC RUBBERS.
By HARRY BARRON (Pirelli-General Cable Works).
Chapman & Hall, Ltd.

A comprehensive survey of the entire subject as it stands at the present time. All the leading commercial types of synthetic rubber-like material are dealt with, particularly in relation to natural rubber.

The book discusses, first, technical and economic considerations; then explores the fundamental chemistry and physics of the subject; finally it deals with the technology of the numerous individual types of synthetic rubber-like material, including Russian products, the German Buna rubbers, and the numerous American products: Neoprene, Thiokol, Buna, Hycar, Chemigum, Butyl rubber, etc.

SEEING IS BELIEVING.
By R. O. ACKERLEY (G.E.C. Illuminating Engineering Dept.).
Presidential Address, Trans. I.E.S., January, 1943.

The address deals with the art of presenting technical information on the subject of lighting as an essential aid to vision in a manner designed to be easily comprehensible to the layman.

ARTIFICIAL LIGHTING.
By R. O. ACKERLEY (G.E.C. Illuminating Engineering Dept.).
An Address to the R.I.B.A., Jour. R.I.B.A., p. 74, February, 1943.

The address suggests with what part of the technical lighting field architects should make themselves familiar. It outlines the essential factors of the physiology of the eye, and the physics of lighting and lighting psychology with which an architect should be concerned.

THE BASIC REQUIREMENTS FOR HEALTH AND COMFORT IN BUILDINGS.
By R. O. ACKERLEY (G.E.C. Illuminating Engineering Dept.).
An Address to the R.I.B.A., The Architect & Building News, pp. 39—40, July 16th, 1943.

This address carries as a sub-heading "The Application of Artificial Light," and shows how the basic artificial lighting requirements for health and comfort are met by the proper design and use of lighting fittings.

FLUORESCENT LIGHTING IN WARTIME BRITAIN.
By R. O. ACKERLEY (G.E.C. Illuminating Engineering Dept.).
Electrical Engineering (America), May, 1943.

This article, which is sponsored by the Ministry of Information, shows the effect which the advent of war had on the development of fluorescent tubular light sources in this country and the extent to which they are being used for furthering the war effort, with special reasons making for their adoption.

* **A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, Birmingham, 6.**